TRILOBITES OF THE UPPER CAMBRIAN (MARJUMAN) PIKA FORMATION OF THE SOUTHERN CANADIAN ROCKY MOUNTAINS

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By

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ABSTRACT

The Upper Cambrian Pika Formation in the southern Canadian Rocky Mountains forms a complete lithologic Grand Cycle. The overall pattern of deposition is one of shallowing upwards from a subtidal, muddy, storm-influenced basin to a shallow carbonate bank. The Pika passes gradationally into the overlying inter- to supratidal siliciclastics of the Arctomys Formation. This transition probably reflects a fall in relative sea level.

Twenty seven collections from three sections yielded trilobites. The faunas are assigned to two low-diversity biofacies: the *Marjumia* - *Spencella* Biofacies and the *Glyphaspis* - menomoniid Biofacies. In contrast to biofacies of deeper, open-shelf environments, such as the Wheeler and Marjum formations of Utah, the Pika biofacies lack agnostid trilobites. Consequently, agnostid-based zonations defined elsewhere in North America cannot be applied to the Pika and a new sequence of three zones and one informal fauna is proposed for use in inner shelf facies.

Eleven species belonging to six genera are described and illustrated. The species *Marjumia bagginsi* is new. Other genera present are: *Bolaspidella, Knechtelia, Glyphaspis* and *Spencella*, in addition to a number of indeterminate forms.

ACKNOWLEDGEMENTS

I would first like to express my gratitude to my supervisor, Steve Westrop, without whom this project would never have been completed, much less started.

Many individuals contributed time and resources towards the completion of this project. From Brock University: Divino Mucciante developed most of the negatives, Candace Kraemer produced thin sections, Bill Parkins and Denis Tetreault provided technical assistance with specimen preparation and Mike Lozon aided the visual production of the thesis. I thank in particular Scott Rose, who provided able and entertaining field assistantship. Rick Cheel and Francine McCarthy provided constructive comments on the preliminary drafts and Brian Pratt, external examiner for the thesis, also made numerous helpful suggestions. James Tremblay of McMaster University provided general technical assistance and constructive comments on the preliminary drafts. Rolf Ludvigsen of the Denman Institute for Research on Trilobites provided technical assistance with specimen preparation. Dr. J.D. Aitken and Dr. W.H. Fritz of the Geological Survey of Canada provided unpublished section information and fossil collections that were crucial to this project.

The Natural Sciences and Engineering Research Council of Canada funded the project throuh a grant to Dr. Westrop. Parks Canada and the wardens of Banff, Jasper and Yoho National Parks gave permission for the project work on their land.

Lastly, I would like to express my gratitude to my family whose continued support and assistance enabled this project to be completed.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

A complete sequence of Lower Cambrian to Middle Ordovician strata is exposed in the southern Canadian Rocky Mountains. These beds are, in places, over 3000 metres thick and consist largely of alternating siliciclastic and carbonate units, many of which are fossiliferous. The Cambrian section comprises 14 formations (see fig. 1) and represents one of the thickest such sections in North America.

The Cambrian stratigraphy was first examined by the Geological Survey of Canada in the 1870's (Gabrielse and Yorath 1992) and lithostratigraphic studies have been published since by Walcott (1912, 1928), Deiss (1939,1940,1941), and more recently by Aitken (e.g. 1966, 1971). Current and previous work is summarised by Gabrielse and Yorath (1992) in the DNAG volume. The paleontology and biostratigraphy of the Pika Formation has received little attention in previous work. Trilobites with tentative identifications were mentioned in published sections by Deiss (1939) and Aitken (1966), and Fritz (1984) briefly discussed the biostratigraphy of the Pika Formation in a symposium guidebook.

Studies of other strata of comparable ages from Utah and Wyoming have focussed on deeper water facies (e.g. Robison 1964a), which contain trilobite faunas that differ from those of shallow water sequences such as the Pika. Trilobite biostratigraphy of the shallow shelf facies in North America is, in general, poorly known (Resser 1938, Deiss 1939, Lochman and Hu 1960). The Pika Formation has been assigned to the *Bolaspidella* Zone of Lochman and Wilson (1958), primarily based on correlation of over- and underlying units with the deep shelf, agnostid - rich faunas of Utah and southern Wyoming (Robison 1964b). As Robison (1976) pointed out, the faunas of the inner shelf siliciclastic and carbonate facies and the deeper shelf facies differ considerably. Accordingly, a new zonal scheme will be required for inner shelf units such as the Pika Formation.

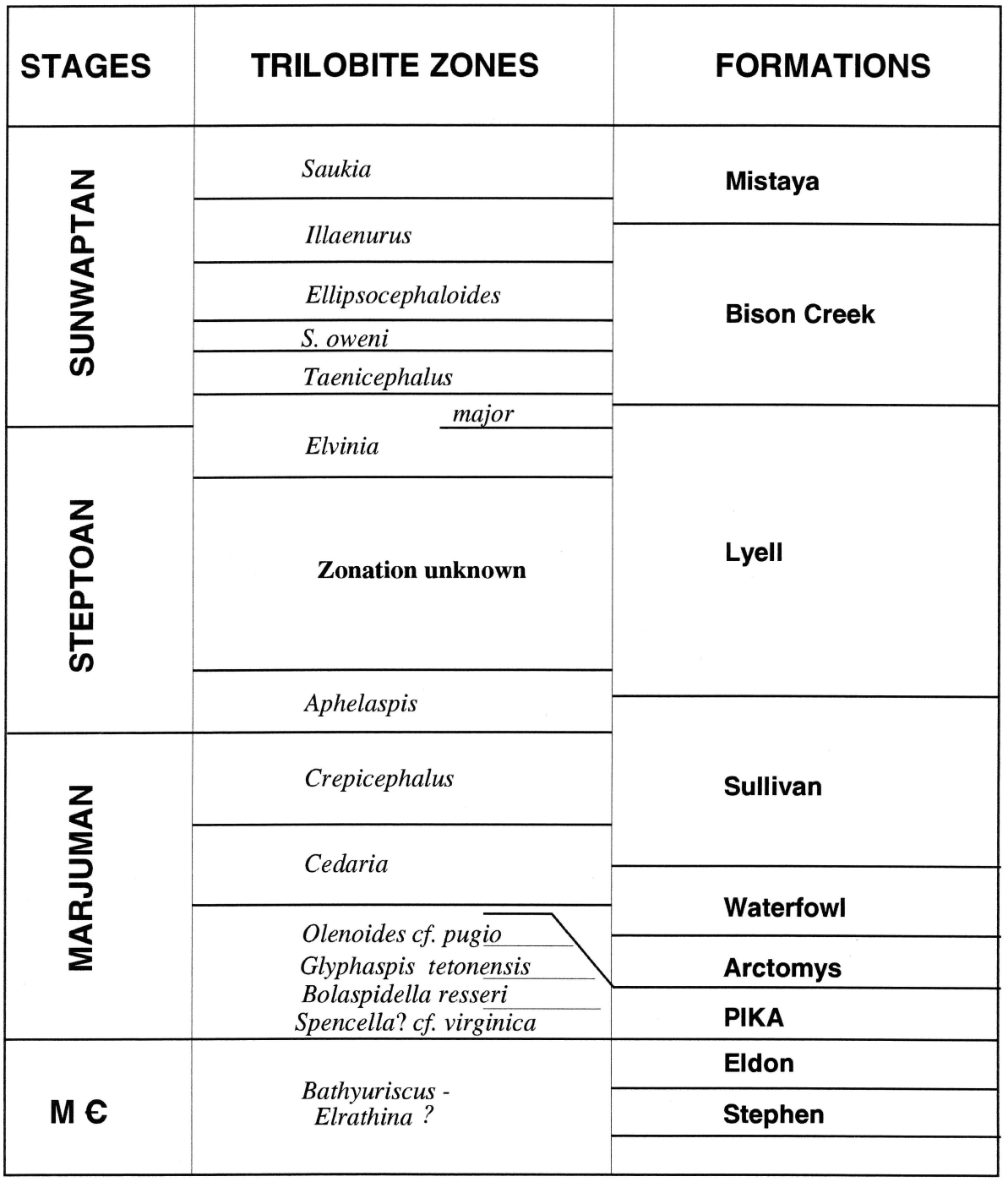


Figure 1 - Stratigraphic section and trilobite zonation of the Middle to Upper Cambrian section in the Southern Canadian Rocky Mountains. (after Aitken et al. 1972 and Westrop 1986).

The purpose of this thesis is to describe and illustrate the poorly known faunas of the Pika Formation as exposed in the Banff - Jasper area of Alberta, and to erect a biostratigraphic zonation for the inner shelf facies. The classification of Upper Cambrian trilobites, particularly the ptychopariids which characterise the Pika Formation and correlatives, is in need of much revision, some of which is presented in this thesis. Additionally, biofacies structure and regional correlation will be examined.

The trilobites were collected in July - August of 1991 from three sections (Roche Miette, Mount Weed and Exshaw, see fig. 2). Additional undescribed material from two other sections (Chaba River and Windy Point), collected by Fritz and Aitken of the Geological Survey of Canada in the mid - 1960's was also included. The sections measured by Aitken at the latter locations were also used in bio - and lithostratigraphic analysis. Published sections by Deiss (1939) were also used for correlations.

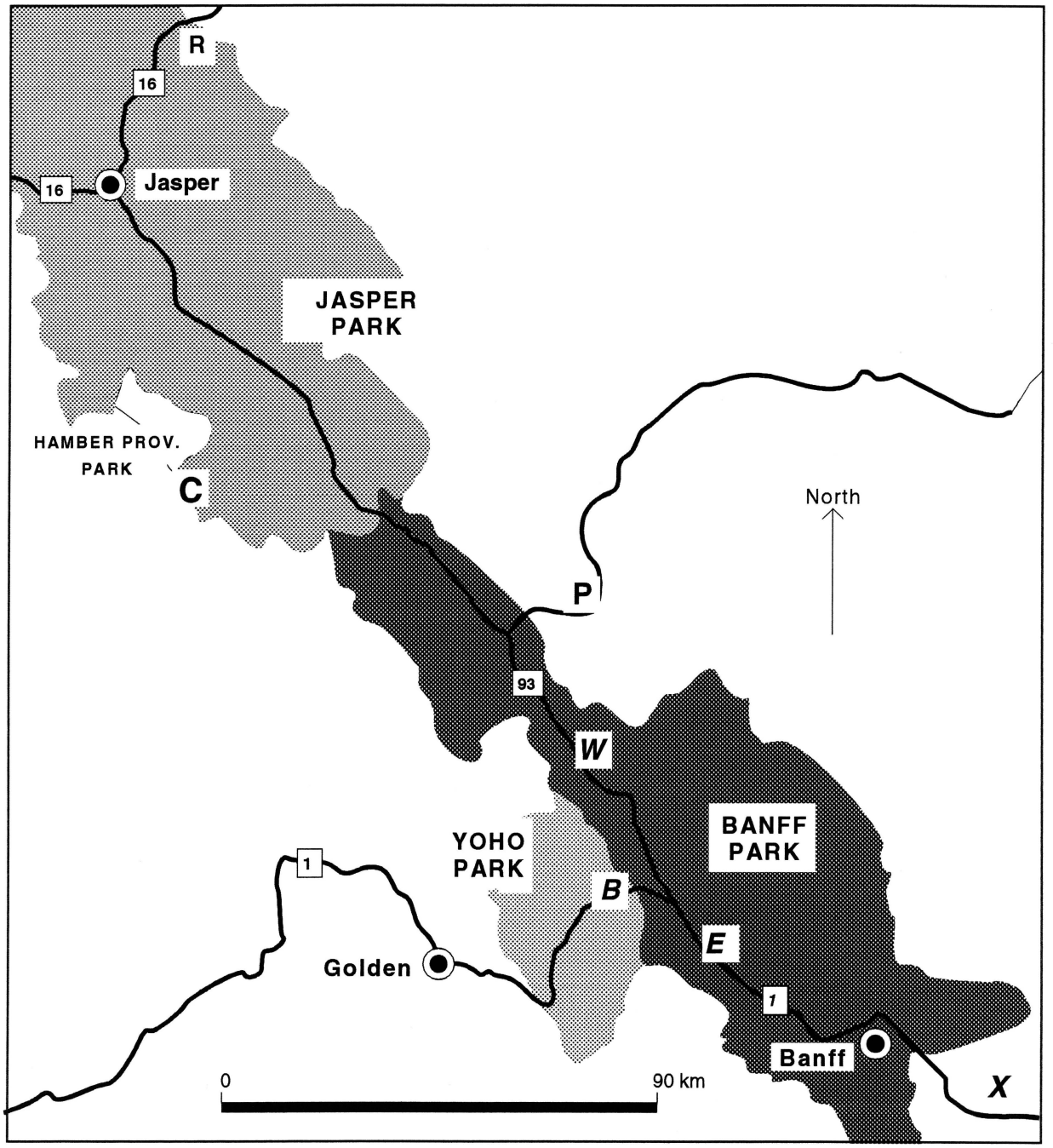


Figure 2 - Location of sections used in this study.
Sections examined during 1991: R,X,W(Roche Miette, Exshaw and Mount Weed.) Sections described by Aitken and Fritz: C,P (Chaba River and Windy Point). Data from Deiss (1939): E,B (Mount Eisenhower and Mount Bosworth).

CHAPTER 2

STRATIGRAPHY & SEDIMENTARY FACIES

Stratigraphic Setting

During most of the Paleozoic, the western edge of North America was occupied by a passive margin, formed after Late Proterozoic to Early Cambrian rifting had isolated the North American craton (Gabrielse and Yorath 1992). Carbonates and clastics were deposited in a miogeosynclinal setting, accumulating a great thickness of sediments.

The Middle and Upper Cambrian rocks of the southern Canadian Rocky Mountains are formed of Grand Cycles (Aitken 1966): packages of alternating shale-dominated units and carbonate-dominated units (see fig. 3). A similar cyclic clastic-carbonate pattern is recognised in the Cambrian Carrara Formation in the Great Basin (Palmer and Halley 1979), and large scale cycles are also apparent in the carbonate-dominated Cambrian Port-au-Port Group in Newfoundland (Chow and James 1987).

To explain the Grand Cycles, Aitken (1966) referred to Palmer's (1960) model for the pattern of facies in the Great Basin. Palmer described three facies belts that ran parallel to the craton margin: the inner detrital belt, formed of terrigenous clastics, the middle carbonate belt, formed of shallow water carbonates, and the outer detrital belt, formed of deeper water clastics. Aitken suggested that the Grand Cycle pattern resulted from the migration of facies belts in response to relative rises and falls in sea level.

Palmer and Halley (1979) interpret the Grand Cycles in the Cambrian Carrara Formation in the southern Great Basin slightly differently. In their model, carbonate deposition was initiated on the margin of a subsiding shelf. The carbonates prograded slowly as the sea level continued to rise. A sudden drop in the rate of sea level rise allowed the carbonates to expand rapidly outwards from the depocentre until a bank of peritidal islands and subtidal shoals was formed. The bank then proceeded to prograde shorewards over the clastics. Eventually, the expanding

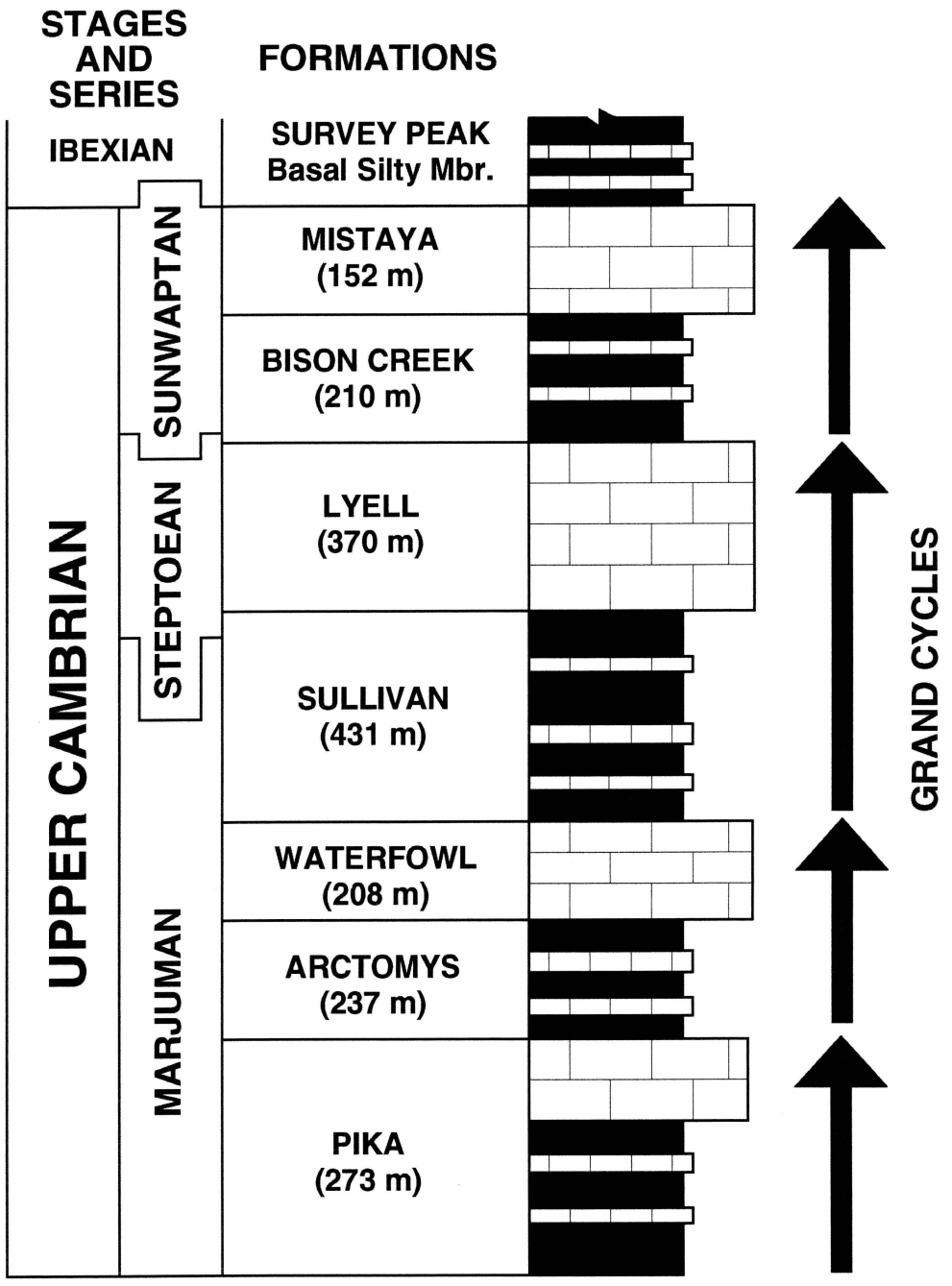


Figure 3 - Generalized lithologic section of the Upper Cambrian of the Rocky Mountains demonstrating large scale cyclicity (after Westrop 1989).

peritidal wedge smothered the subtidal region of profuse carbonate production (" the carbonate factory "), inhibiting further growth. With the cessation of carbonate production, terrigenous clastics were able to expand across the subsiding shelf, initiating the shaly half - cycle of the succeeding Grand Cycle.

The Palmer - Halley model predicts the occurrence of peritidal carbonates in the upper portion of the carbonate half - cycle. However, Westrop (1989) demonstrated that this model does not apply to the Bison Creek - Mistaya Grand Cycle of the southern Canadian Rocky Mountains, where peritidal carbonates occur in the middle of the cycle in the cratonwards sections instead of at the top.

The Pika Formation (Deiss 1939) is a complete Grand Cycle with a lower half - cycle of shales and thin carbonate interbeds and an upper half - cycle of shallow water carbonates. The Pika thickens towards the west, from 60 metres thick at Exshaw to 333 metres thick at Chaba River, accompanying a rise in carbonate content. The westernmost occurrences, (e.g. Mount Bosworth [Deiss 1939]) contain little shale, so that the Grand Cycle can not be recognised (Fig. 4). In the subsurface, the Pika Formation ranges well out under the eastern plains, with little change in thickness, although the lithology becomes increasingly sandy (Aitken 1966).

The Pika Formation Grand Cycle does not conform exactly to any existing model. The overall geometry, with thick carbonates in the west and shallow water terrigenous muds in the east, is comparable to that of the Carrara Formation. However, there is relatively little evidence of peritidal environments in the east, where the sections are topped by massive grainstones and parted limestones. Peritidal facies, such as planar cryptalgal laminites occur in the middle of the Mount Weed section instead of at the top, as the Palmer-Halley model predicts.

All of the models for Grand Cycle formation have the cycle ending with a relative deepening of sea level, either by increased subsidence or eustatic response. The top of the Pika Formation in all sections is overlain by the Arctomys Formation, which consists of distinctive purple shales with mudcracks and salt hopper casts indicative of subaerial exposure due to lowering of the sea level. This suggests that an increase in the clastic influx may have

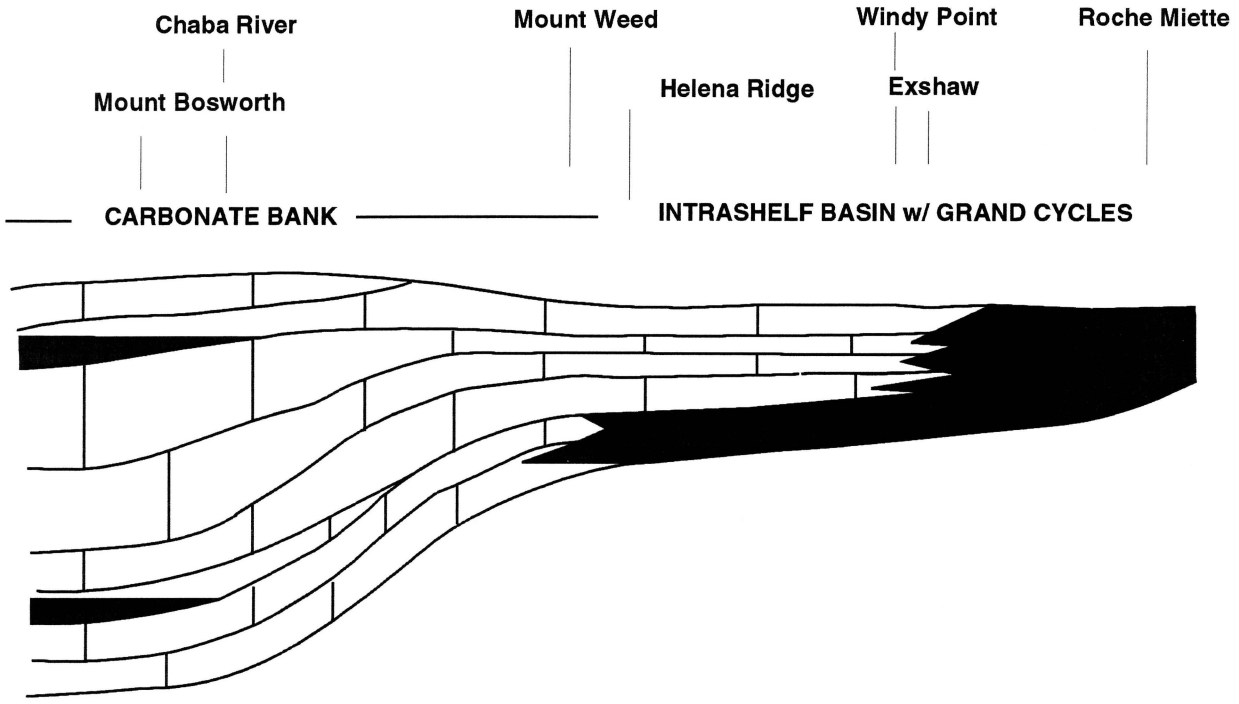


Figure 4 - Basin reconstruction model with division between carbonate bank and intrashelf basin.[Mt. Bosworth and Helena Ridge sections from Deiss (1939), Windy Point section from Aitken (1968), Chaba River section from Aitken (unpub.)]

smothered the carbonate bank and ended the carbonate half - cycle. In the Chaba River section in the west, the appearance of dark shales near the top of the Pika suggests that there may have been deepening before the onset of the Arctomys clastics.

SEDIMENTARY FACIES

Introduction

A detailed study of the sedimentology of the Pika Formation is beyond the scope of this thesis. However, observations made during the course of field work do allow a preliminary facies analysis to be made. The objective of this work is to establish a general paleoenvironmental framework, within which the distribution of trilobites may be evaluated.

Lithofacies

The following eight lithofacies were identified in the field:

Mudstones with carbonate tempestite interbeds - Thin to thick bedded (5 - 50+ cm), light green, tan or grey shales to mudstones. Primary sedimentary structures such as laminations are absent. Interbeds of 1 - 3 cm thick, planar to lenticular bioclastic wackestones to packstones comprise approximately 15% of each unit. The bioclasts are frequently concentrated on the upper and/ or lower bedding surfaces.

Unfossiliferous shales - 1 metre+ thick dark green shales that exhibit no apparent primary sedimentary structures and are frequently tectonically sheared.

Interbedded calcisiltites and lime mudstones - packstones - Interbedded calcisiltites and lime mudstones to packstones (5 - 15 cm thick). Occasional concentrations of straight horizontal to sub - horizontal burrows occur at the bottoms of beds. Individual beds may be crudely graded, with concentrations of large bioclasts on lower bedding surfaces (see fig. 5). Beds are often arranged in overall coarsening-upwards units 5-8 metres thick.

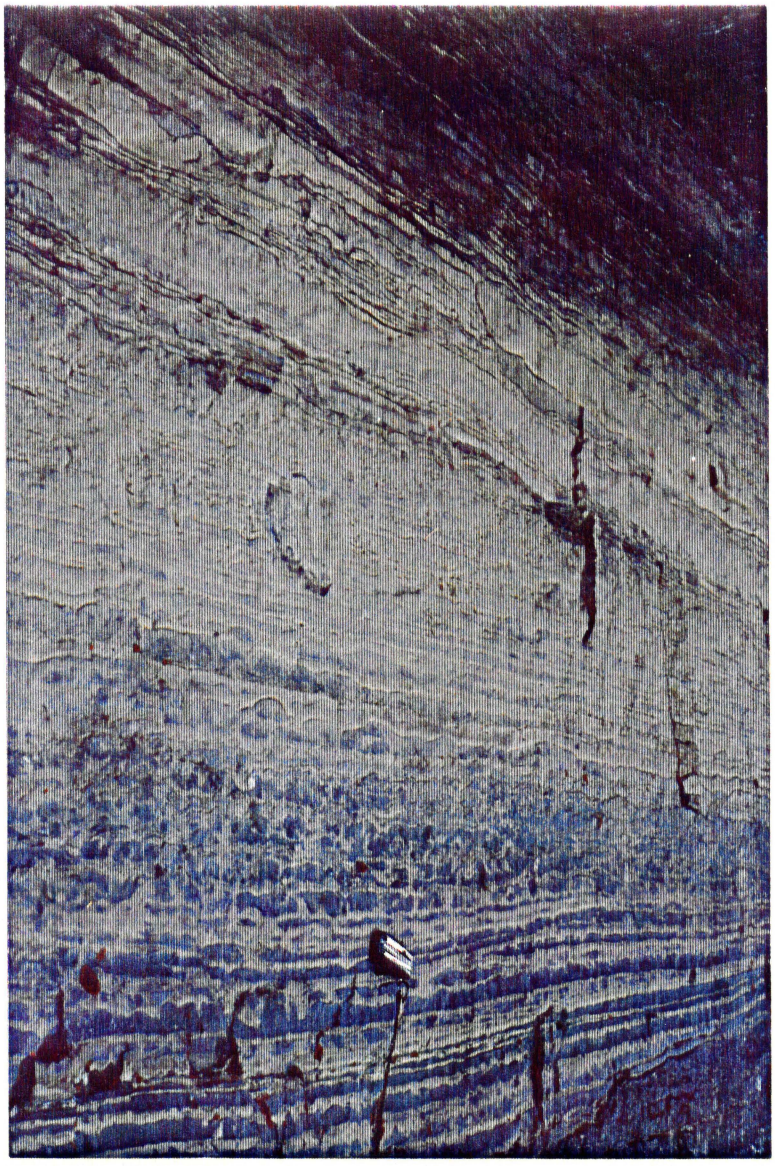


Figure 6 - Photograph of the "parted limestone" facies from the Exshaw section.

Thick-bedded grainstones - Heavily dolomitised, orange to yellow weathering thick bedded (20-50 cm) to massive grainstones, which appear to have been originally intraclastic. Primary sedimentary structures are not evident.

Banded or nodular " parted limestones " - Grey or tan weathering, banded lime mudstone - packstone couplets which are separated by thin shaly or dolomitised partings. Bedding is planar to nodular. Similar lithofacies, generally referred to as "parted limestone", have been documented by other workers in the southern Canadian Rocky Mountains (Aitken 1966) and Newfoundland (Chow and James 1987) (see fig. 6).

Flat pebble conglomerates - Thin (3 - 5 cm) beds of flat pebble conglomerates. Clasts are thin and tabular, and usually formed of lime mudstone. Matrix is invariably dolomitised.

Oolitic packstones - Rare, thin (5 - 20 cm) beds of orange weathering dolomitised oolitic packstones with no primary sedimentary structures evident.

Microbial laminites - Thin (5 - 10 cm) beds of planar microbial laminites, with thick domal and digitate stromatolites in Chaba River section only.

Lithofacies Associations

The lithofacies described above occurred in the following lithofacies associations:

Lithofacies association A - This association occurs in the lower portion of the Pika Formation in the eastern sections (Roche Miette, Windy Point, Mount Weed, Exshaw) and it is expressed as cycles. The lower part of each cycle is a 20+ metre thick interval of mudstones with thin carbonate interbeds (see fig. 7). The interbeds are thin, bioclastic packstones with

Figure 5 - Photograph of a bioclast covered lower bedding surface in lithofacies association A from the Roche Miette section.

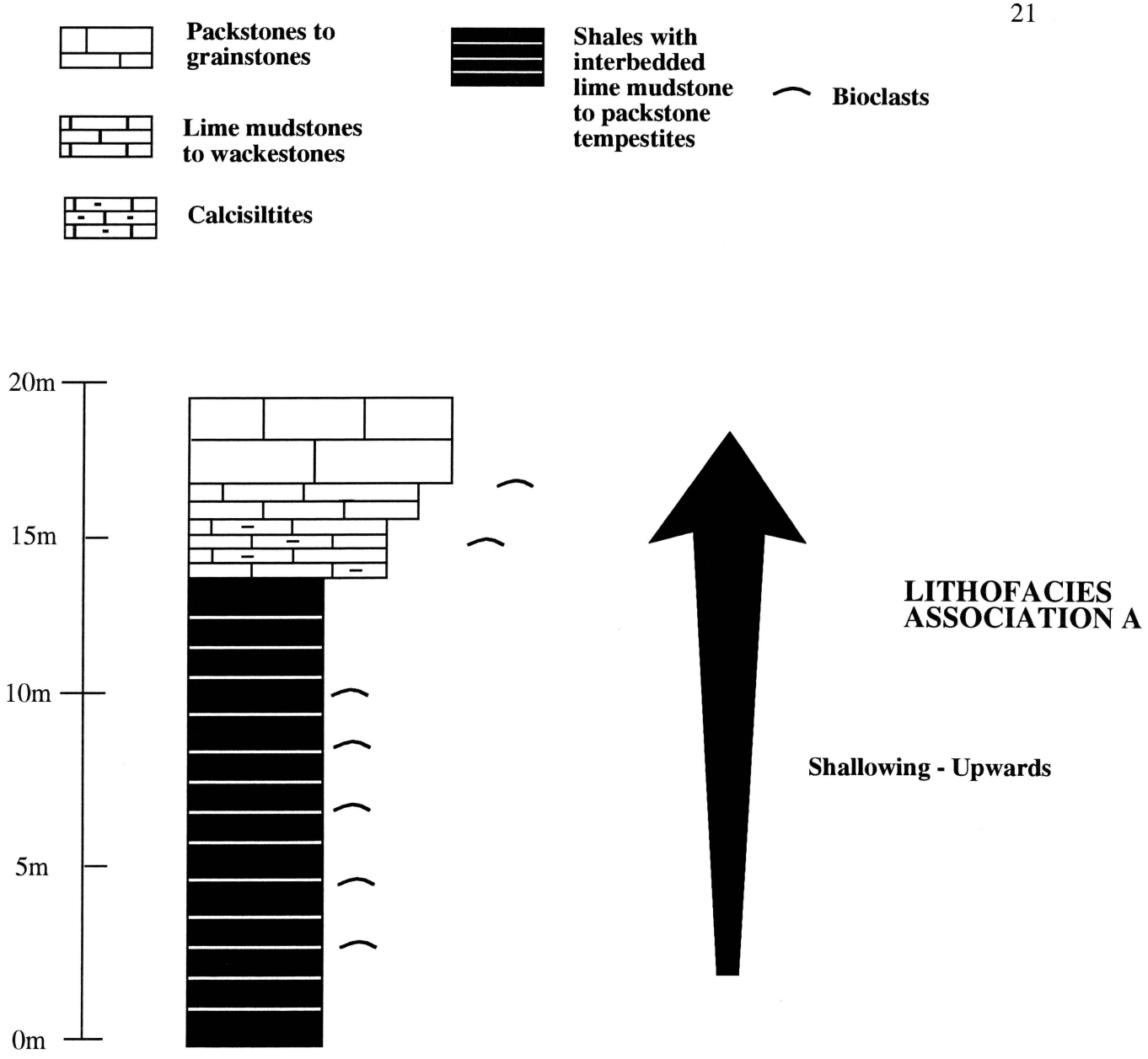


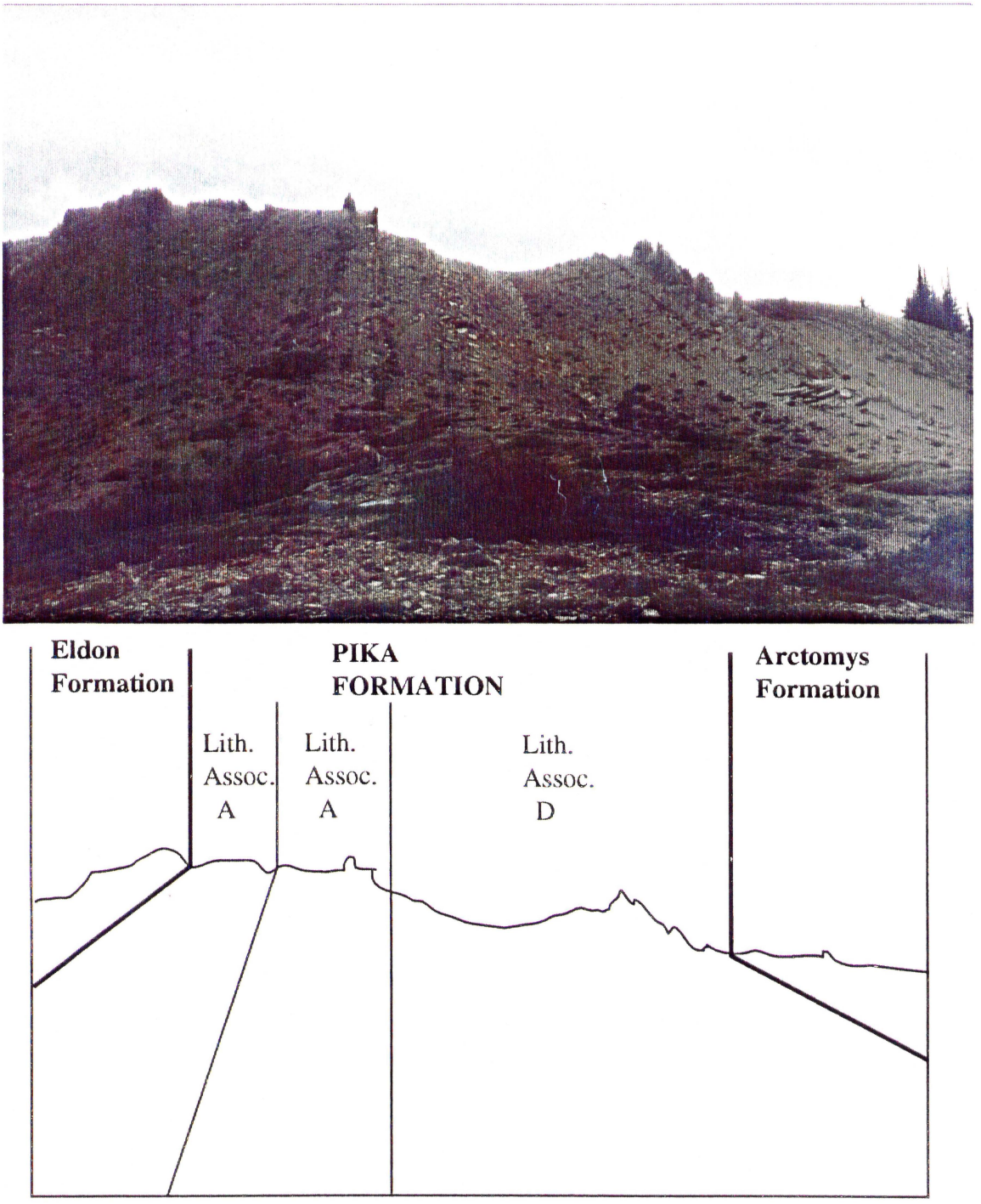
Figure 7 - A typical lithologic log of lithofacies association A, demonstrating overall clearing and shallowing upwards character. (from 1.5-20.4m, Roche Miette section)

sharp bases. They record periods of high energy in an otherwise quiet, muddy subtidal shelf, so that it is likely that the beds are tempestites (Kreisa 1981, Aigner 1982) and represent relatively distal storm facies (Aigner 1982, 1985). Above the mudstones is a 2 - 10 metre thick, coarsening upwards interval of calcisiltites with graded bioclastic packstones which are interpreted as recording deposition in a shallower setting. However, at all times, deposition appears to have between storm and fair weather wave base because thick, amalgamated carbonate sands of very shallow aspect (e.g. Kreisa 1981, Aigner 1982, 1985) are not present.

Two vertically stacked cycles of lithofacies association A occur in the lower half of the eastern sections (Roche Miette, Windy Point, Exshaw, Mount Weed) and are best exposed at Roche Miette (see figs. 8, 8a).

Lithofacies association B - Lithofacies association B consists of thick-bedded to massive grainstones with rare, thin interbeds of oolite packstones, planar microbial laminites, and domal and digitate stromatolites (see fig. 9). The presence of planar microbial laminites is frequently indicative of deposition under peritidal conditions (Aitken 1967, James 1984) so that it is probable that lithofacies association B represents a mosaic of shallow water carbonate bank environments (e.g. Pratt and James 1986) including carbonate sand shoals and carbonate islands. Lithofacies association B occurs above association A at Mount Weed, Exshaw, Windy Point and Chaba River where it reaches a maximum thickness of over 100 metres. It is not present at Roche Miette.

Lithofacies association C - Lithofacies association C forms the upper portion of the Pika Formation at Mount Weed, Exshaw and Windy Point). It consists of a thick section (up to 120 m thick) dominated by parted lime mudstone - packstone couplets with occasional interbeds of massive, dolomitised grainstones. (see fig. 10) The parted limestones are similar to lithologies described by other workers (e.g. Aitken [1966], Chow and James [1987], Westrop [1989]) from the Rocky Mountains and Newfoundland. Opinion on the environment of deposition of



Figures 8 and 8a- Photograph and schematic drawing of the Roche Miette section of the Pika Formation, showing formational boundaries and lithofacies associations.

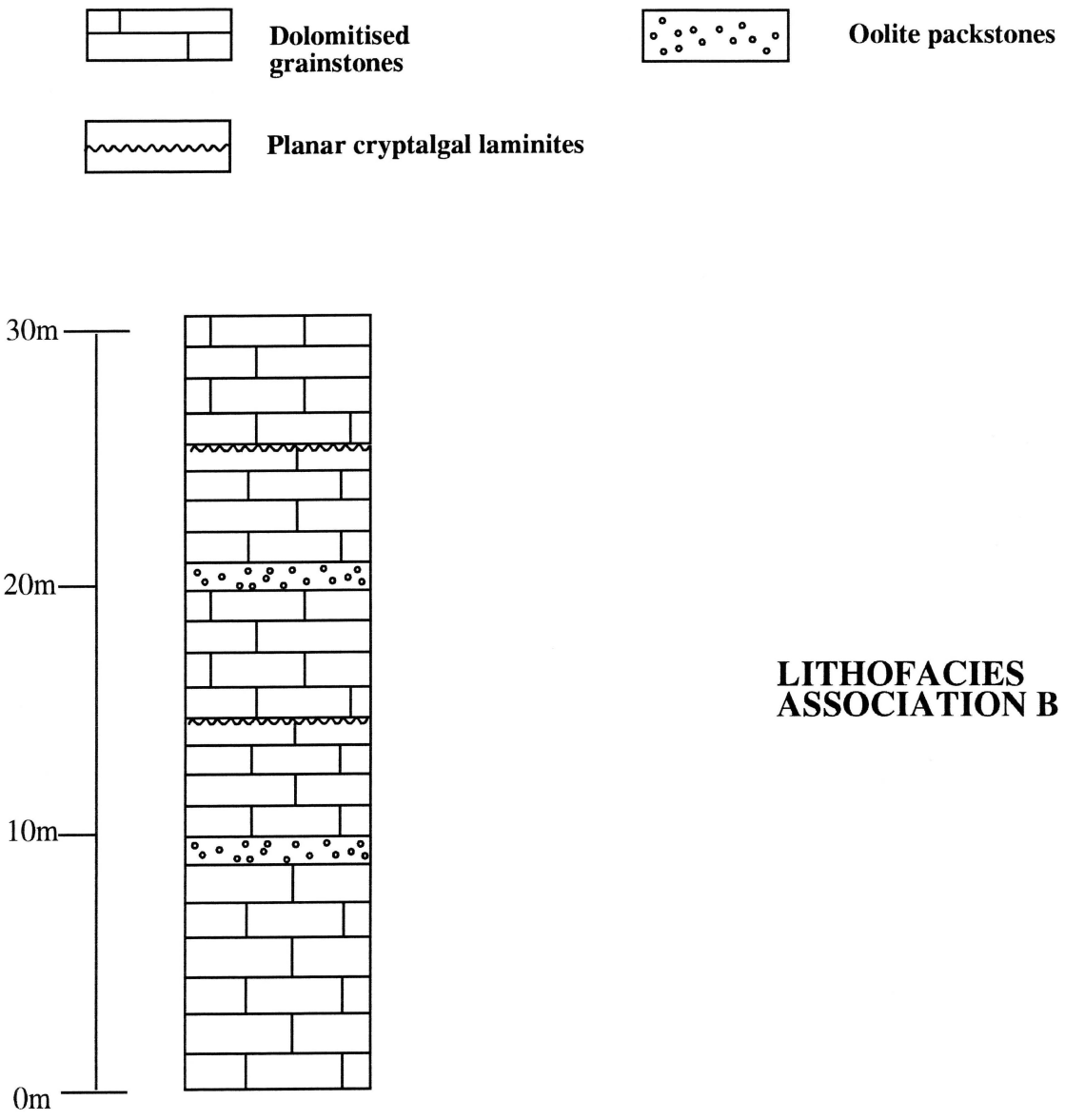


Figure 9 - A typical lithologic log of lithofacies association B (from 85-115m of Mount Weed section).

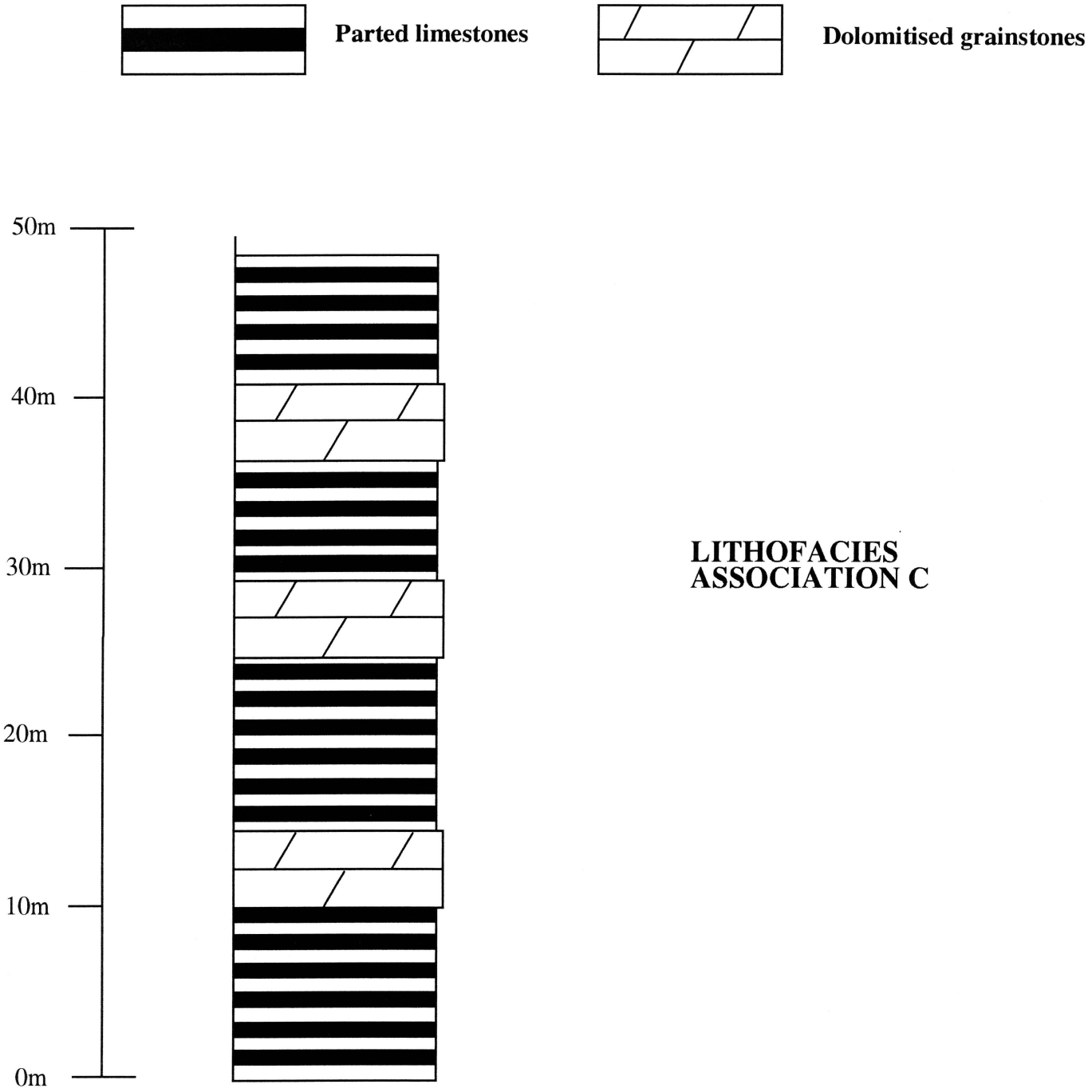


Figure 10 - A typical lithologic log of lithofacies association C showing predominantly "parted limestone " with interbedded grainstones. (from 150-200m Mount Weed section)

parted limestone varies from shallow, intertidal environments (Aitken 1966, Chow and James 1987) to slightly deeper subtidal shelf (Westrop [1989], Cowan and James [1989]). The subtidal origin model is more likely appropriate for the Pika Formation as the parted limestones lack evidence of peritidal origin (e.g. mudcracks, cryptalgal laminites etc.)

Lithofacies association D - Lithofacies D is only expressed at the Roche Miette section, and forms the upper 35 metres of the Pika Formation. The lithology is dominantly dark green shales with minor dolomitised grainstones and flat pebble conglomerates (see fig. 11) Absence of primary sedimentary structures makes interpretation difficult, but given that the Pika Formation as a whole records a shallowing - upwards pattern and the overlying Arctomys Formation at Roche Miette is formed of inter - to supratidal flat muds, it is possible that this association represents shallow, subtidal mudflats, with occasional storms depositing the carbonates.

SUMMARY

The Pika Formation records an overall shallowing upwards sequence. The lower part of the formation records the existence of a shallow muddy shelf that was rimmed by a zone of carbonate deposition. In the muddy shelf "basin", periodic storms are recorded by a variety of tempestites, including bioclastic packstones and flat pebble conglomerates. As the sea level fell, the carbonates prograded and aggraded. Carbonate deposition expanded cratonwards covering the muddy shelf and forming a mosaic of peritidal to subtidal environments extending across most of the platform except to the northeast (Roche Miette) where clastic deposition continued.

Unlike other Grand Cycles (Aitken 1978, Westrop 1989) which ended with a rise in relative sea level, the Pika Cycle was terminated by a drop in sea level and is overlain by inter- to supratidal clastics of the Arctomys Formation.

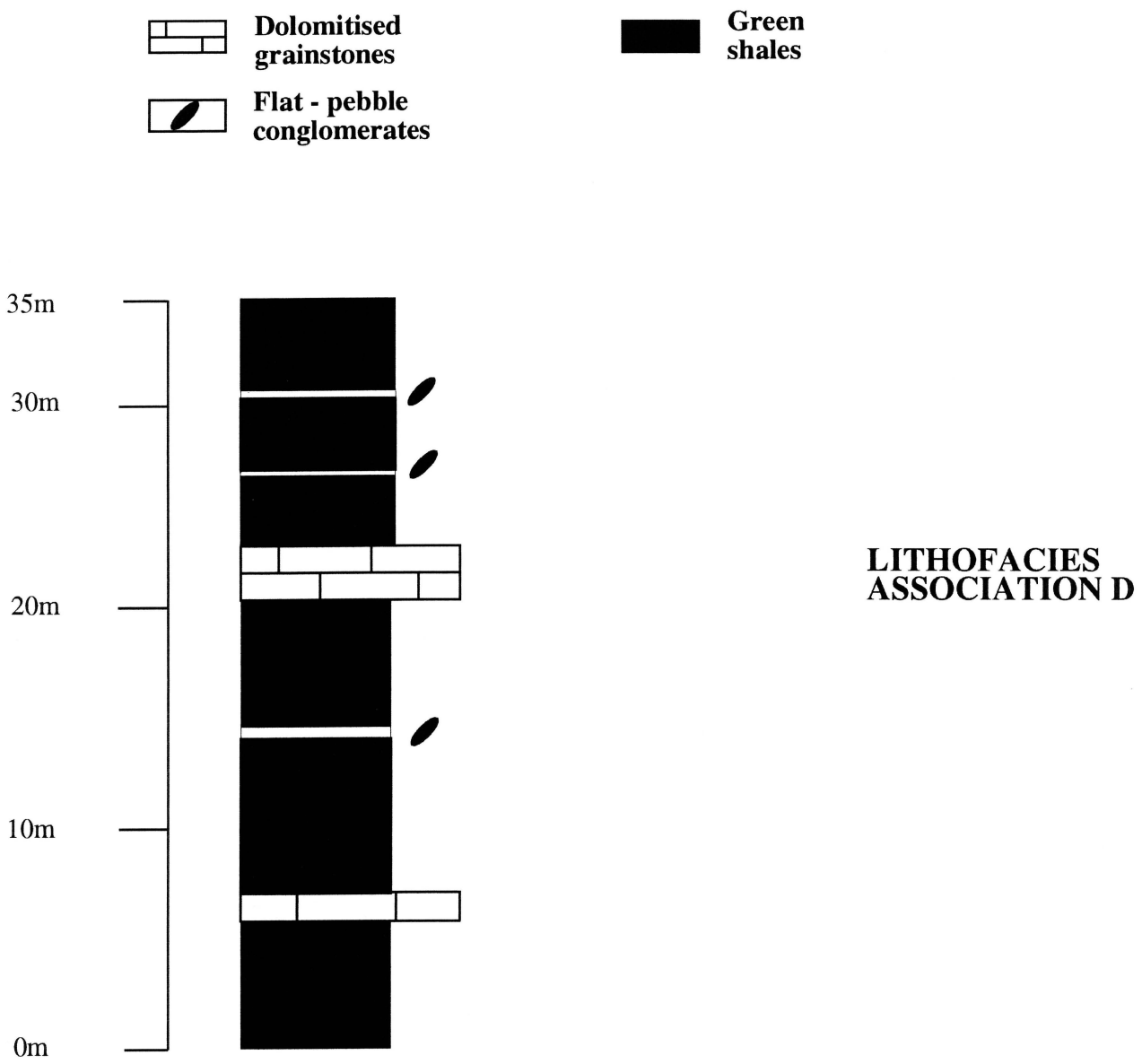


Figure 11 - A typical lithologic log of lithofacies association D. (From 44-79m, Roche Miette section)

CHAPTER 3

BIOSTRATIGRAPHY

Introduction

The " traditional " North American biostratigraphic column for the Upper Cambrian is based on polymeroid trilobites, primarily from outer detrital belt environments. This scheme places the Pika Formation in the *Bolaspidella* Zone, which is best described from the Wheeler and Marjum Formations of the House Range of Utah (Robison 1964a). Intercontinental or interprovincial correlation usually uses an agnostid - based zonation, and the Pika Formation has been correlated with the *Ptychagnostus atavus* Zone based on extrapolation from the underlying Eldon Formation (Ludvigsen and Westrop 1983).

Robison (1976) demonstrated in Cambrian rocks in the Great Basin that the outer detrital belt contained different (agnostid-rich) trilobite faunas from the inner detrital belt and the zonation for one facies belt would not apply to others. The outer detrital belt zonation cannot be applied to the Pika Formation, which is formed of inner detrital facies and biofacies, and lacks agnostids. Robison (1976) erected the *Ehmaniella* zone, based on restricted-shelf polymeroids, that spans the entire *Bathyuriscus - Elrathina* zone and most of the *Bolaspidella* zone of outer-shelf polymeroids. However, none of these taxa is present in the Pika, and a new zonation, specific to the lithofacies and biofacies present, is proposed. A comparable approach was used by Tremblay and Westrop (1991), who established a new zonation for shallow water carbonate litho- and biofacies in the Middle Ordovician of the Mackenzie Mountains. Ludvigsen et al. (1986) demonstrated that genera tend to be characteristic of biofacies and that a vertical zonation should be based on species.

Zones and Faunas

A sequence of three zones and one informal fauna is established from species range data (see figs. 12, 13, 14, 15).

The *Spencella*? cf. *virginica* Zone:

The lower boundary of the *Spencella*? cf. *virginica* Zone coincides with the base of the formation in the eastern sections, and is defined by the first appearance of the eponymous species. *Marjumia* is the dominant taxon in the *Spencella*? cf. *virginica* Zone, with *M.* cf. *transversa* characterising the western section and *M. bagginsi* characterising the eastern sections. *Spencella* cf. *montanensis* occurs with *S.*? cf. *virginica* in the Windy Point section. It is not clear whether this apparent spatial differentiation of species of *Marjumia* reflects ecologic controls, or whether it is simply due to the relatively small number of samples from each section. The *Marjumia* - *Spencella* Biofacies (see Biofacies section) contains all faunas of the *Spencella*? cf. *virginica* Zone.

The following taxa occur in the *Spencella*? cf. *virginica* Zone:

Spencella? cf. *virginica*

S. cf. *montanensis*

Marjumia cf. *transversa*

M. bagginsi

Gen. and sp. indet. 1

The *Spencella*? cf. *virginica* Zone can not be easily correlated with any other Cambrian section except by extrapolation from over - and underlying units. *Spencella virginica, S. montanensis* and several species of *Bolaspidella* and *Marjumia* occur in the Cambrian boulders in the Levis Conglomerate at Metis, Quebec (Rasetti 1963), but the lack of shared species renders any correlation between the two formations tentative at best.

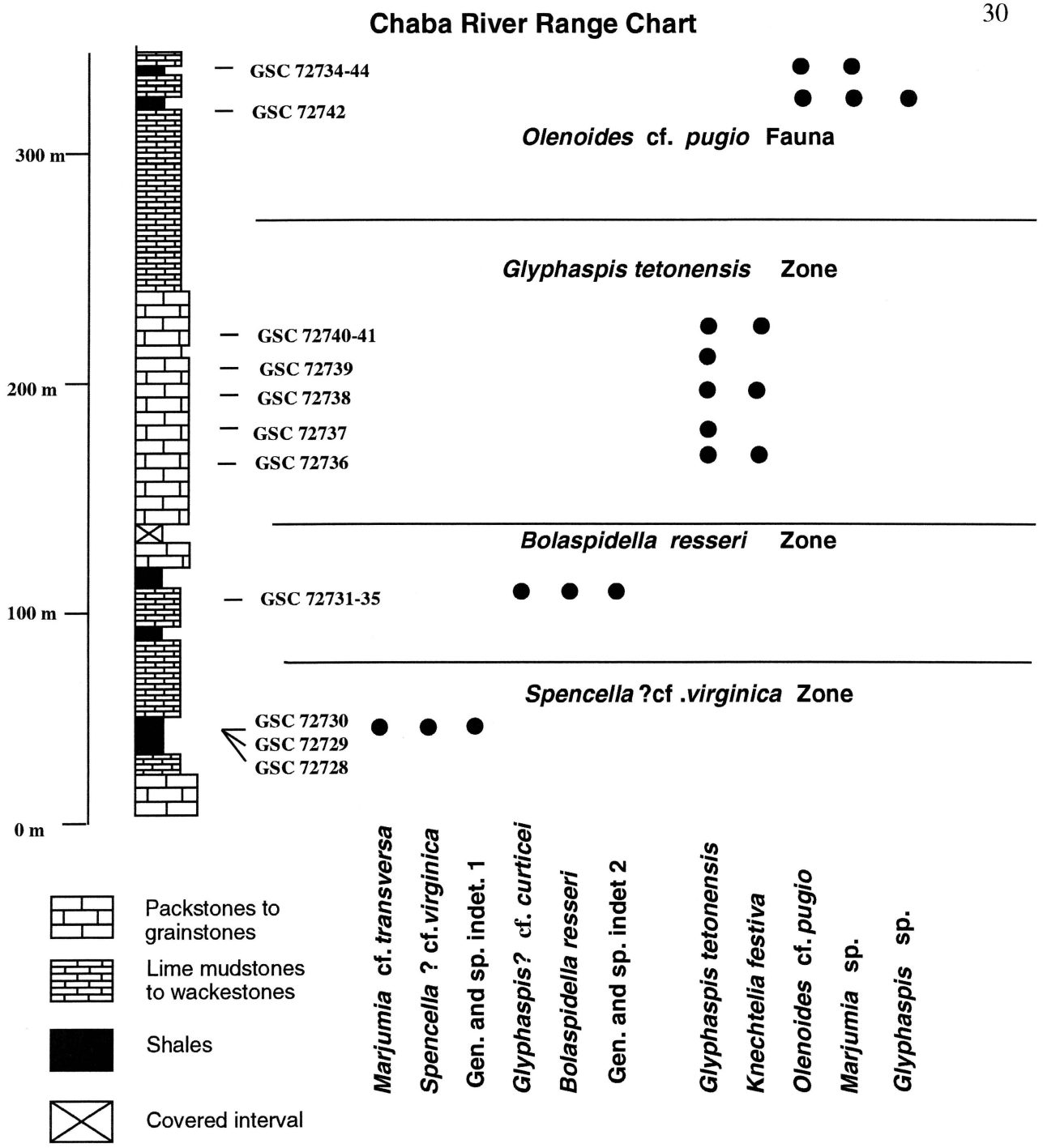


Figure 12 - A simplified lithologic log of the Chaba River section of the Pika Formation showing the location of the fossil collections and the range of the trilobite species. The section was measured by J. D. Aitken of the G.S.C. and only differentiates between thin and thick bedded carbonates and shales. (see Appendix C for detailed section)

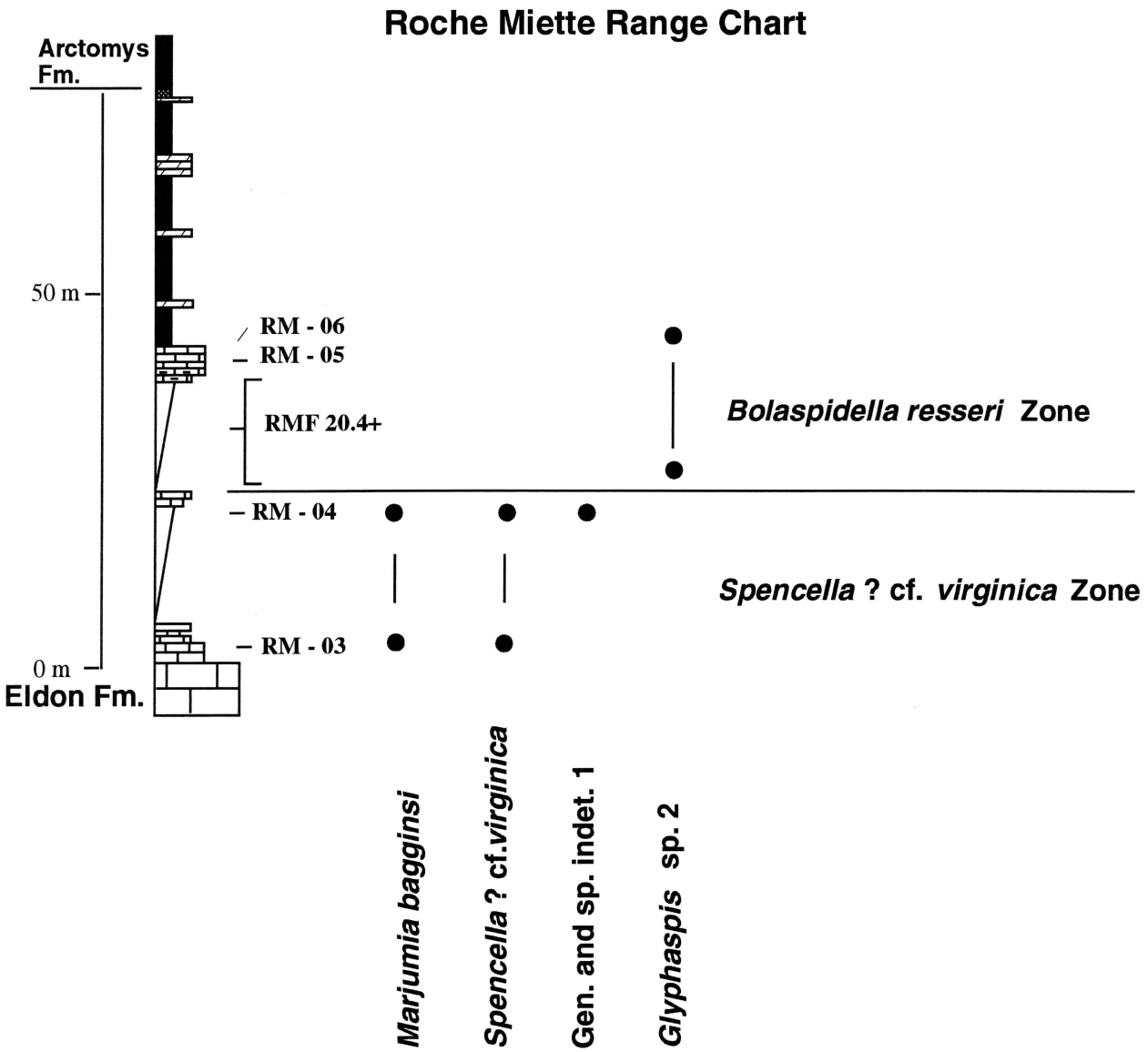


Figure 13 - A schematic diagram of the Roche Miette section of the Pika Formation showing the location of the fossil collections and the range of the trilobite species. (see figure 12 for legend and Appendix A for detailed section)

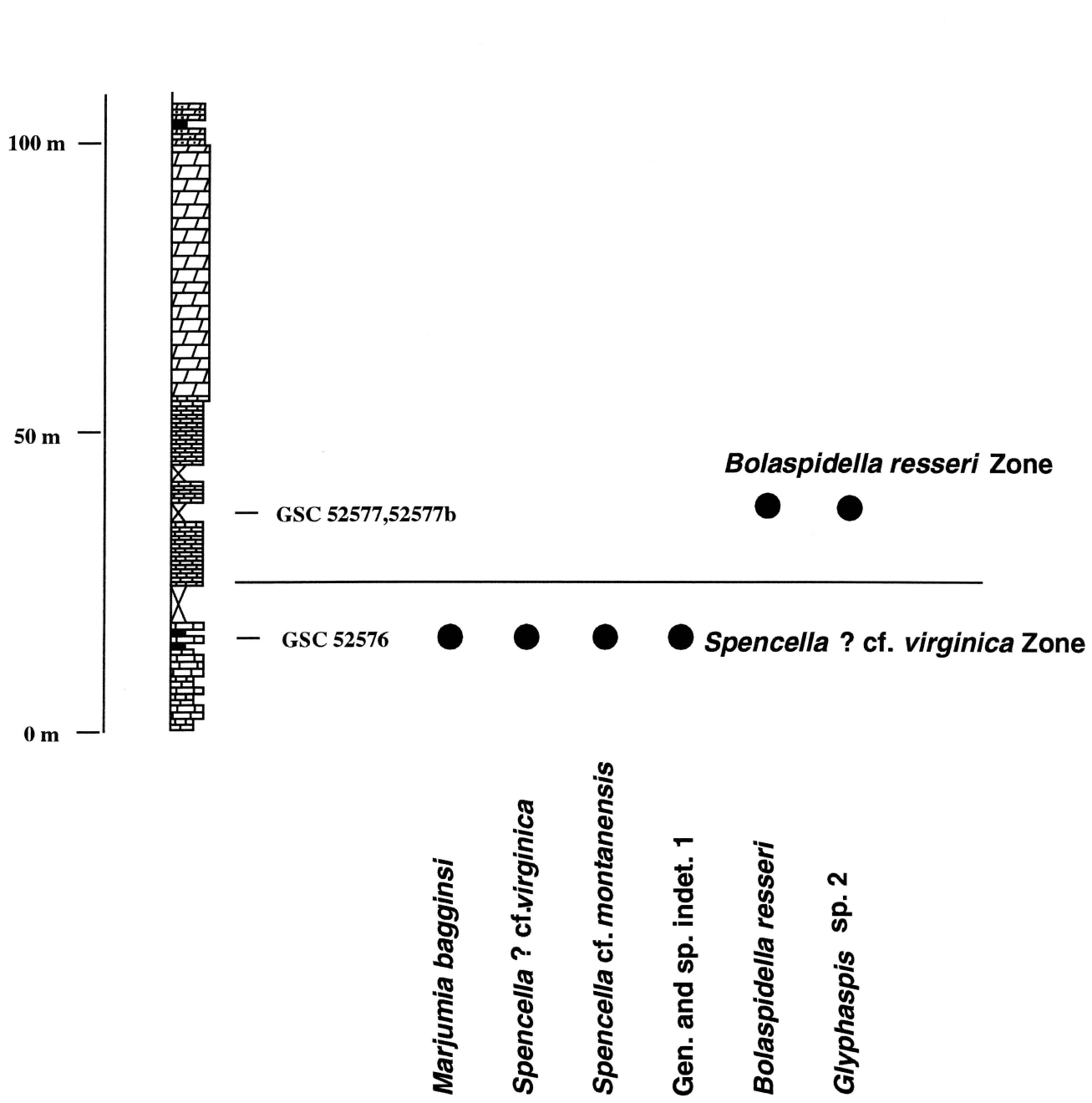


Figure 14 - A schematic diagram of the Windy Point section of the Pika Formation showing the location of the fossil collections and the range of the trilobite species. (see fig. 12 for legend and Appendix B for detailed section)

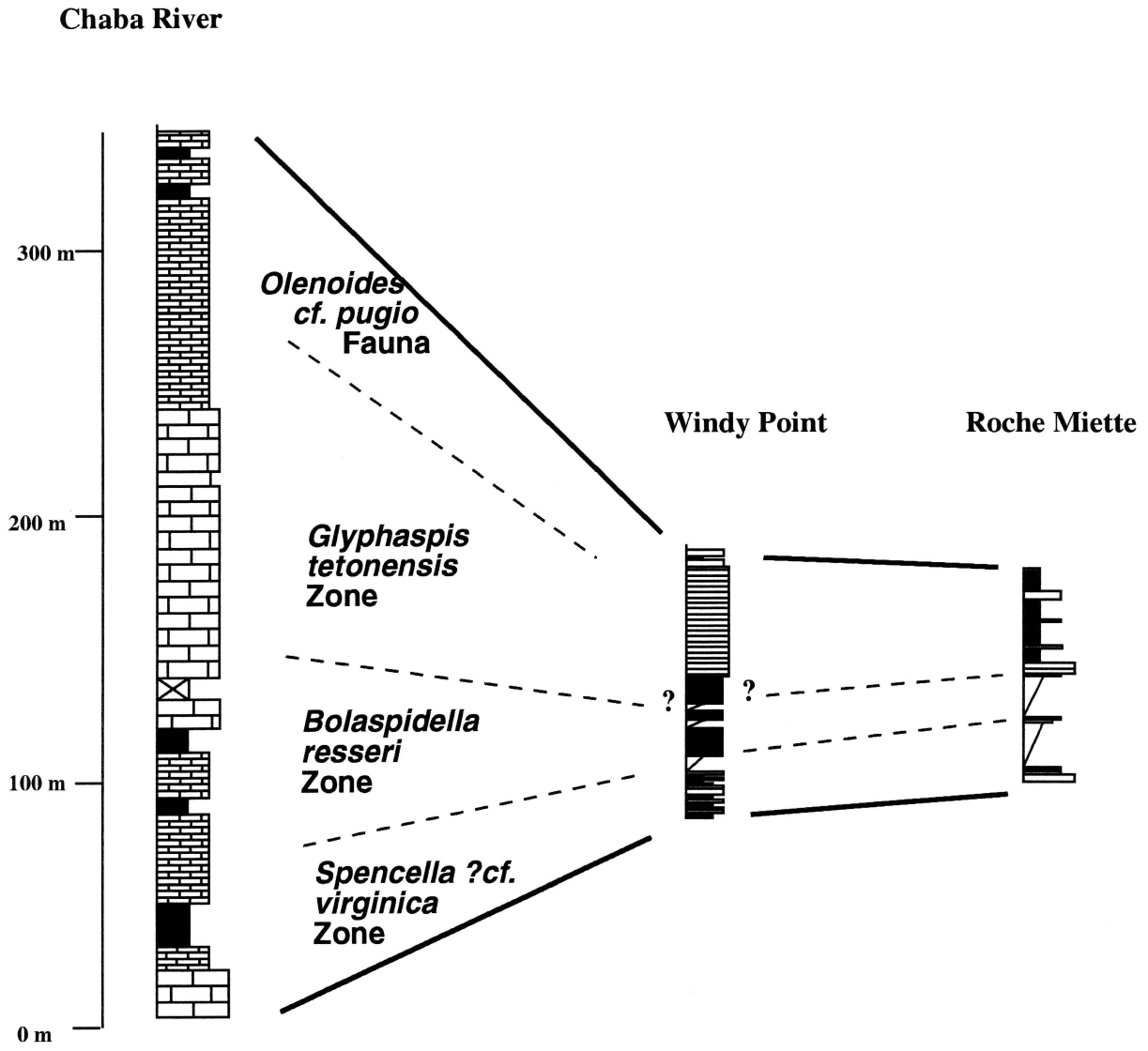


Figure 15 - Biostratigraphic correlation of the zones and faunas of the Pika Formation. (Solid lines = formational boundaries, dashed lines = zonal boundaries)

The *Bolaspidella resseri* Zone:

The lower boundary of the *Bolaspidella resseri* Zone is defined by first occurrence of the eponymous species. In the eastern sections, *Glyphaspis* sp. 2 is the dominant species present, while at Chaba River, *Glyphaspis?* cf. *G? curticei* is the most common taxon. The *Bolaspidella resseri* Zone is restricted to the *Glyphaspis* - menomoniid Biofacies.

The following taxa occur in the *Bolaspidella resseri* Zone:

Bolaspidella resseri

Glyphaspis sp. 2

Glyphaspis? cf. *curticei*

Gen. and sp. indet. 2

The *Bolaspidella resseri* Zone is correlable with the lower Death Canyon Limestone of the Gros Ventre Group in northwestern Wyoming, which also contains the eponymous species. *Bolaspidella contracta* Robison (1964a), which occurs in the Marjum Formation of the Great Basin of Utah and Wyoming, is similar to *Bolaspidella resseri*, and may prove to be a synonym. Additionally, an unidentified trilobite from the *Bolaspidella contracta* Subzone (Gen. and sp. indet. 2, Robison 1964a) is probably conspecific with Gen. and sp. indet. 2 from the *B. resseri* Zone from the Pika Formation. This suggests a correlation between the *Bolaspidella resseri* Zone of the Pika Formation and the *Bolaspidella contracta* Subzone (Robison 1964a) in the lower Marjum Formation.

Additional evidence for a correlation between the Pika and the Marjum formations can be obtained by considering the underlying formations. The Wheeler Shale, which underlies the Marjum, records a "major" transgression with outer shelf shales appearing above shallow shelf limestones; the base of this formation has been correlated with the *Ptychagnostus gibbus* Zone (Robison 1964b, 1984). The Eldon Formation, which immediately underlies the Pika Formation in the Rockies, is dominantly formed of middle carbonate belt dolostone except at its westernmost extent, in Yoho National Park, British Columbia, where the Field Member, or " black band " occurs (Aitken 1981). The " black band " is formed of thin platy black shales and

represents an incursion of the outer detrital belt facies. The trilobite fauna has been correlated with the *Ptychagnostus gibbus* Zone (Robison 1984), suggesting that the black band and the base of the Wheeler Shale of Utah record the same transgressive event (although deepening in Utah is partly influenced by syndepositional faulting[Rees, 1986]). The base of the Pika Formation must, therefore, be younger than the base of the Wheeler, contrary to previous implications by Ludvigsen and Westrop (1985) and Westrop (1992).

The *Glyphaspis tetonensis* Zone:

The *Glyphaspis tetonensis* Zone is only definable in the Chaba River section, as the corresponding portions of the eastern sections are barren of fossils; the first occurrence of *G. tetonensis* marks the base. *G. tetonensis* is the most abundant species, and *Knechtelia festiva* is the only other species present. The *Glyphaspis tetonensis* Zone contains species from the *Glyphaspis* - menomoniid Biofacies.

Glyphaspis tetonensis and *Knechtelia festiva* are present in the upper Death Canyon Formation of the Gros Ventre Group in Wyoming (Lochman and Hu 1960), allowing a definite correlation to be made. The Corner - of - the - Beach Formation in eastern Gaspé has yielded a fauna that includes a single pygidium that is nearly identical to those assigned to *Glyphaspis tetonensis.* The Corner - of - the - Beach contains no other trilobites that are conspecific with those of the Pika, so that a correlation between these formations is tentative.

The *Olenoides* cf. *pugio* Fauna

The *Olenoides* cf. *pugio* Fauna is only defined in the Chaba River section. Due to the small number of collections and specimens available, a formal zone has not been erected for the upper Pika Formation. The base is defined as the first occurrence of *O.* cf. *pugio*, which is also the most abundant species present.

The following taxa occur in the *Olenoides* cf. *pugio* Fauna:

Olenoides cf. *pugio*

Marjumia sp.

Glyphaspis sp.1

The *Olenoides cf. pugio* Fauna can be tentatively correlated with the Park Shale of the Gros Ventre Group of Wyoming by the occurrence in the Park Shale of two poorly preserved specimens of *Olenoides incertus* (Miller 1936; Shaw 1956; Lochman and Hu 1960) that are similar to *Olenoides* cf. *pugio*.

Correlation with other North American sequences

The Middle Cambrian sequence in Montana (Deiss 1939) contains a diverse fauna, including several species of *Glyphaspis* as well as *Olenoides*. There are, however, no species in common, making a correlation with the Pika Formation difficult. The Montana faunas are probably older than the Pika Formation, as Robison (1964a) correlates them with the *Bathyuriscus - Elrathina* Zone which corresponds to the Stephen and lower Eldon formations in the southern Canadian Rockies.

The trilobites of the March Point Formation of western Newfoundland were divided into an *Olenoides longispinus* Zone and an *Ehmaniella cloudensis* Zone, which were correlated with the *Bathyuriscus - Elrathina* Zone by Knight and Boyce (1987). This correlation was not based upon common trilobite species, and is therefore tentative. James et al. (1989) correlated the March Point Formation with the *Ptychagnostus gibbus* Zone, but, because the March Point lacks agnostids, this correlation is uncertain (see fig. 16).

The trilobite faunas of the Upper Cambrian Rogersville Formation in the southern Appalachians were correlated with the Wheeler and Marjum formations of Utah by Resser (1938), although he provide no detailed support for this conclusion. The Rogersville faunas are characterized by *Ehmaniella* and contain no marjumiids or other trilobite taxa that would permit direct correlation with the Pika Formation.

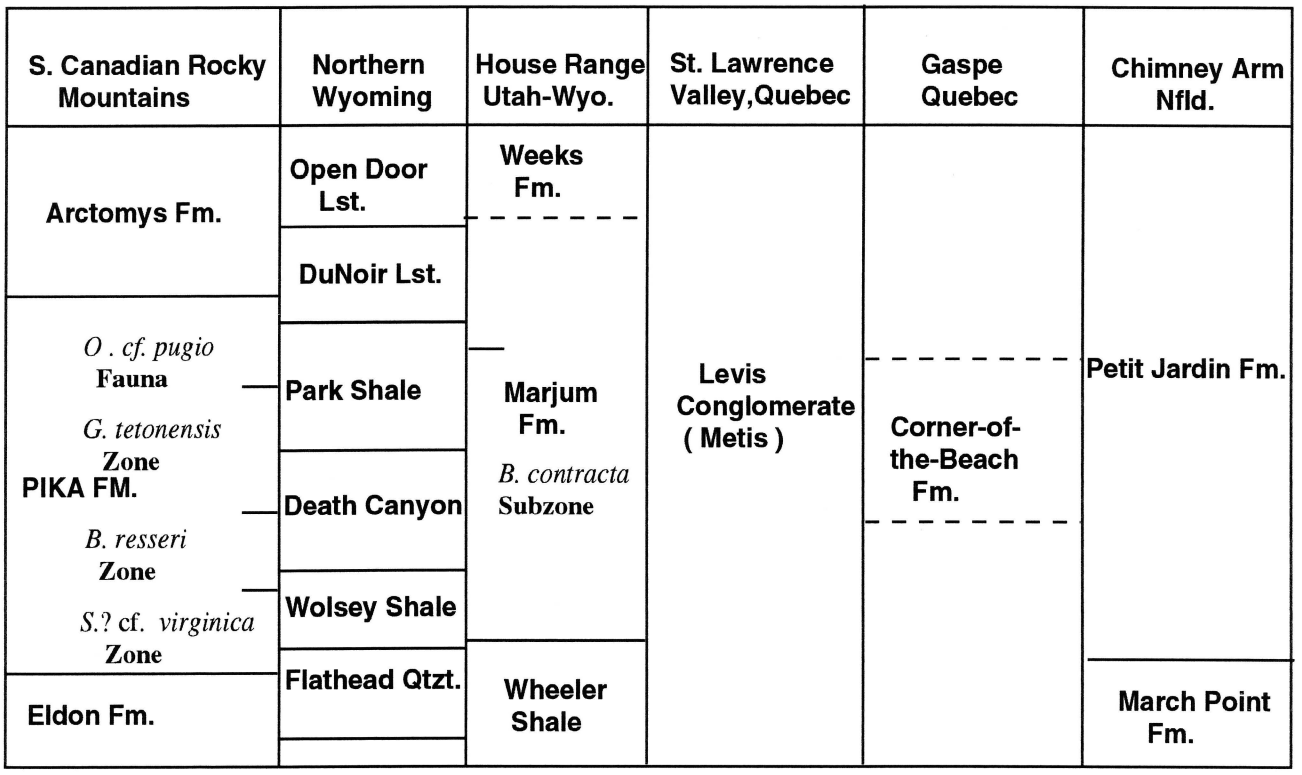


Figure 16 - Correlation of the Pika Formation with other Cambrian sections in North America. (After Westrop 1992, Fritz et al. 1971, Robison 1964, Rasetti 1963, Lochman and Hu 1960 and Miller 1936) (Formational thicknesses not to scale)

Trilobite Biofacies

Trilobite biofacies of the *Bolaspidella* Zone and correlatives have not been studied in detail previously. Because of the small number of collections from the Pika, a statistical analysis of trilobite biofacies will not be attempted. However, a preliminary evaluation can be made from relative abundance data by qualitative comparison of pie diagrams (see figs. 17, 18). Analysis has been performed at the genus level, an approach that has been successful at defining biofacies in Cambrian (Ludvigsen and Westrop 1983, Pratt 1992), Ordovician (Fortey 1975, Ludvigsen 1979, Tremblay and Westrop 1991) and Silurian (Thomas 1977, Tetreault, in press) faunas.

Two biofacies are established in the Pika Formation, the *Marjumia* - *Spencella* and *Glyphaspis* - menomoniid biofacies. Both biofacies are characterised by low species diversity (see fig. 19) and by an absence of agnostid trilobites. In these respects, the Pika biofacies are different from the more diverse, agnostid-rich faunas of the outer detrital belt (e.g. Wheeler Shale/Marjum Formation, Robison 1964a) and carbonate shelf margin settings (Cow Head Group, S.R. Westrop, pers. comm.). They are, however, comparable to older (Mount Whyte Formation, Tremblay 1992) and younger (Eau Claire Formation, S.R. Westrop pers. comm.) inner detrital belt facies, which are also characterised by low species diversity and a general scarcity of agnostid trilobites.

The following biofacies can be defined from the Pika Formation:

The *Marjumia* - *Spencella* Biofacies

All collections assigned to the *Marjumia* - *Spencella* Biofacies are dominated by *Marjumia*, with *Spencella* accounting for 10 - 15% of the total fauna (see fig. 18). The fauna of this biofacies is restricted to the lower shaly facies of the Pika Formation.

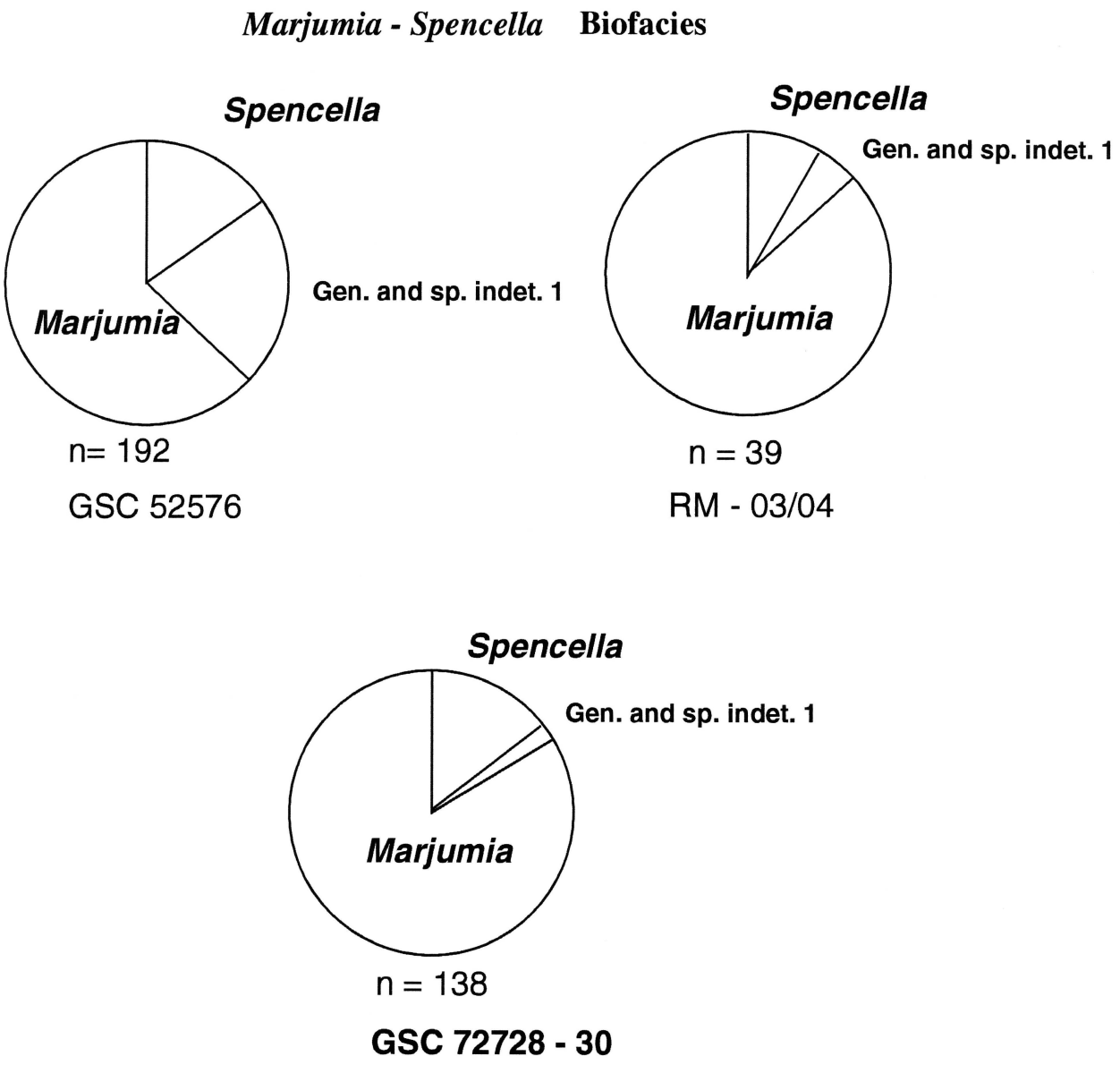


Figure 17 - Pie diagrams of relative abundances of genera in the ***Marjumia - Spencella*** Biofacies.

Glyphaspis - Menomoniid Biofacies

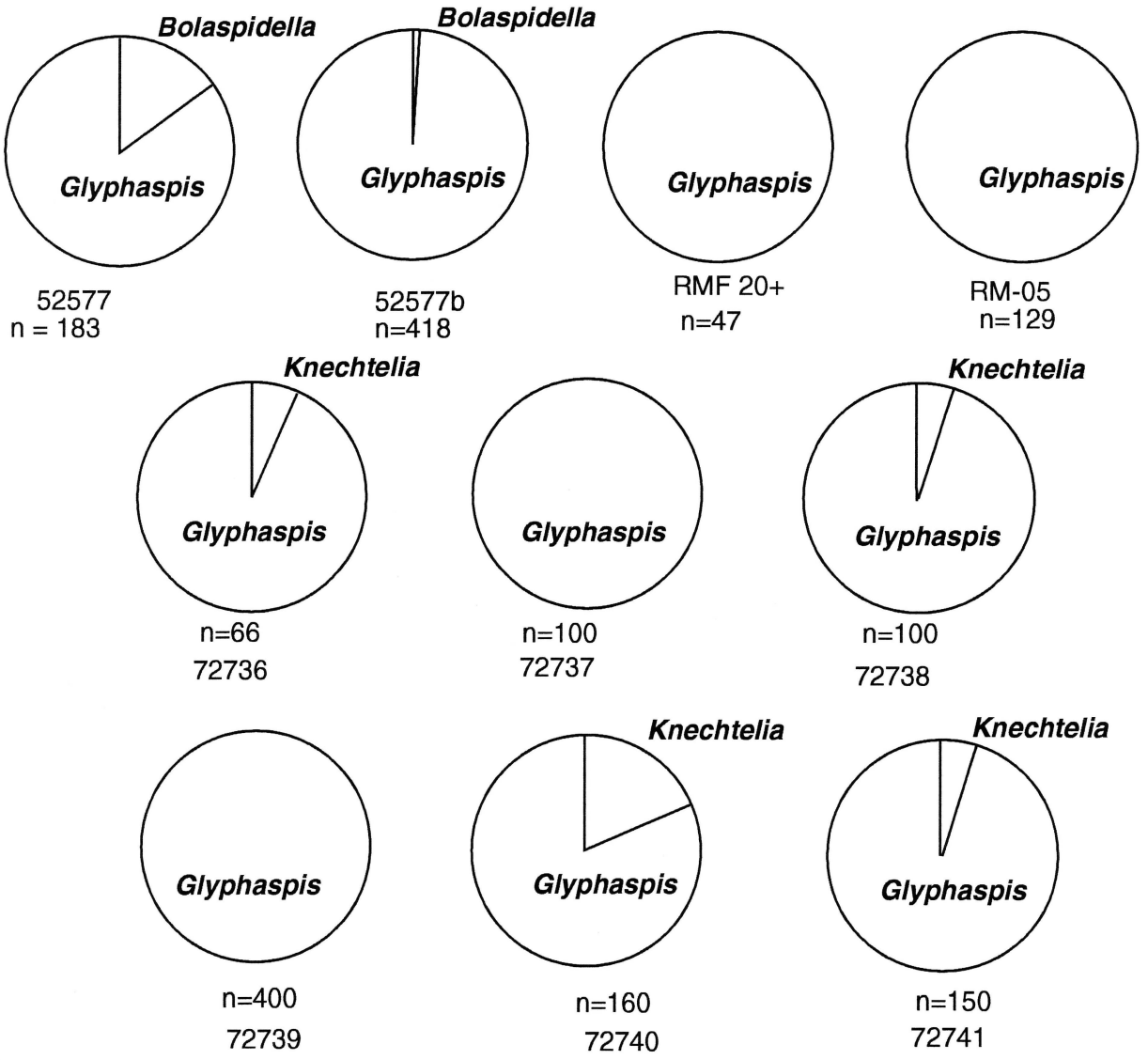


Figure 18 - Pie diagrams showing relative abundances of trilobite genera in collections from the *Glyphaspis* - menomoniid Biofacies.

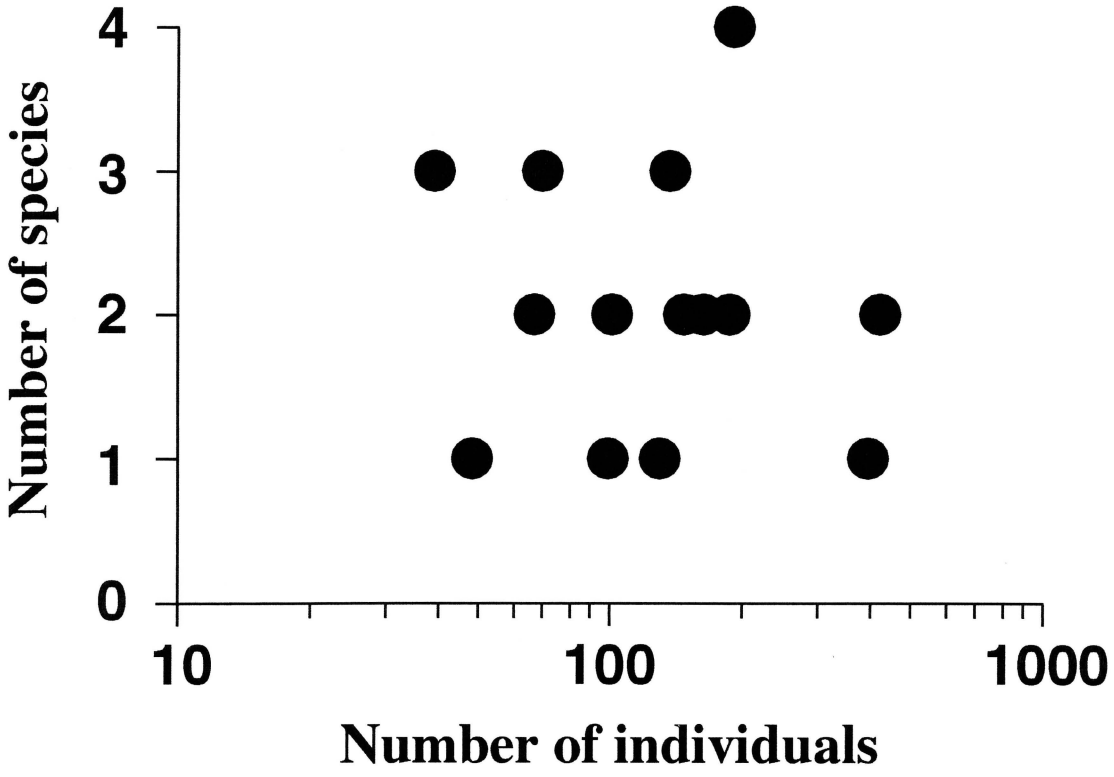


Figure 19. Species diversity of collections used in biofacies analysis. At all sample sizes, diversity is low and ranges from one to four species.

Marjumia occurs elsewhere in the Pika Formation, but not as the dominant component, and not with *Spencella*. *Marjumia* is a common genus in the Wheeler and Marjum formations (Robison 1964a), but the Great Basin faunas contain large numbers of agnostids and ptychopariid genera such as *Elrathia* that are not present in the Pika. These differences reflect the open shelf, outer detrital belt setting of the Wheeler and Marjum, versus the inner shelf facies of the Pika.

The *Glyphaspis* - menomoniid **Biofacies**

The *Glyphaspis* - menomoniid Biofacies is dominated by *Glyphaspis*, with up to 15% of menomoniids, either *Bolaspidella* or *Knechtelia* (see fig. 18), and occurs in both shallow carbonate bank and muddy shelf lithofacies.

At Roche Miette, *Glyphaspis* appears abruptly at the base of the second cycle of lithofacies association A and replaces *Marjumia* as the dominant trilobite genus. This appears to be a case of immigration because *Glyphaspis* has been found in older strata in the Great Basin (Swasey Formation; Robison 1964b).

The *Glyphaspis* - menomoniid Biofacies is probably recorded in the Death Canyon Limestone in northern Wyoming, where *Glyphaspis tetonensis* and *Knechtelia festiva* occur together (Lochman and Hu 1960). However, quantitative data on relative abundances were not published by Lochman and Hu (1960), so that a confident biofacies assignment of their material can not be made. Correlative strata from the Great Basin (Robison 1964a) lack *Glyphaspis*, although the genus has been reported from the older Swasey Limestone (Robison 1964b). However, more data will be needed to confirm the existence of a *Glyphaspis* Biofacies in the Swasey.

The upper Pika Formation faunas are dominantly *Olenoides*, with *Marjumia* as a major component and *Glyphaspis* as a minor component. These faunas may represent a separate *Olenoides* - *Marjumia* biofacies, but more data are required.

SYSTEMATIC PALEONTOLOGY

Repository and Terminology

All of the material will be housed in the Geological Survey of Canada, Ottawa, Ontario, Canada.

The descriptive terminology follows the Treatise on Invertebrate Paleontology (Moore 1959).

Order **CORYNEXOCHIDA** Kobayashi 1935

Family **DORYPYGIDAE** Kobayashi 1935

Genus *Olenoides* Meek 1877

Type species - *Paradoxides? nevadensis* Meek 1870 from the Wheeler Shale of Utah (by original designation).

Diagnosis - Dorypygid with a parallel-sided to anteriorly weakly expanded glabella. Pygidium with 3 to 8 pairs of marginal spines. Interpleural furrows variably impressed on the pygidium. Pydgidial axis long and cylindrical.

Discussion - *Olenoides* has been differentiated from *Kootenia* Walcott, 1889 only on the presence of interpleural furrows on the pygidium (see Palmer 1954). However, interpleural furrows seem to be variably expressed, with faint grooves being visible in photographs of *Olenoides quadriceps* (Hall and Whitfield 1861; Palmer 1954, pl. 14, fig. 3) from the Great Basin and in the photographs of several species of *Olenoides* in Resser (1938, pl. 4, figs. 10, 11, pl. 12, figs. 17, 23) in the Appalachians. *O. magnaformis* Yegorova (Repina and Romanenko 1978, pl. 18, figs. 6 - 11) from Siberia, shows faint, diagonal interpleural furrows, while *O. anomalica* (Repina and Romanenko 1978, pl.18, figs. 12, 15) does not. Chang et al. (1980, pl. 85, figs. 15-18), illustrated *K. sp.* from southern China with definite interpleural furrows. When comparing other characters, specimens previously assigned to *Kootenia* tend to have shorter spines than *Olenoides*, sometimes only triangular projections (Deiss 1939, pl. 17), although, the variation within *Kootenia* is great, from short, blunt spines (*K. buttsi* Resser 1938 pl 7, fig. 17) to long, barely tapering spines (*K. quadriceps*) Palmer 1954, pl. 14, figs. 2, 3). As the only important distinguishing characteristic has been shown to variably expressed in both genera, *Kootenia* is placed in synonymy with *Olenoides.*

Dorypyge, (e.g. *D. richtofeni* Dames; Chang and Jell 1987, pl.12, figs. 4 - 7, pl. 13, figs. 1 - 10, pl. 15, fig. 7), has a pygidium that is slightly sub-trapezoidal but is otherwise similar to that of *Olenoides'*. The cranidium of *Dorypyge* has a somewhat inflated, barrel shaped glabella that tapers both anteriorly and posteriorly. Additionally, the surface of *Dorypyge* is granulose, a feature that is uncommon in *Olenoides*.

Bonnia (e.g. *B. parvulus* Walcott 1916, pl. 57, figs. 1-1c, pl. 64, fig. 6), possesses a cranidium that is similar to *Olenoides*, but its pygidium usually bears only a single short pair of marginal spines and has a broader axis. However, Fritz (1991) has recently expanded the concept of *Bonnia* to include species with up to three pairs of marginal spines (e.g. *B. carnata* Fritz, 1991, pl.5, figs. 7-17). This move greatly reduces the differences between *Bonnia* and *Olenoides*, and it is possible that future work will show that these genera are synonymous. *Holteria* (e.g. *H. problematica* Walcott 1924 (pl.13, figs. 17 - 21), possesses a strongly anteriorly expanding glabella and a pygidium with long, broad spines and a border of variable width.

Olenoides cf. *pugio* (Walcott)

(Pl. 1, figs. 1-6)

Neolenus intermedius pugio Walcott, 1908, p. 35, pl.6, fig. 9 [only].

Neolenus intermedius Walcott, 1908, pl. 6, fig. 7 [only].

Olenoides pugio (Walcott) Kobayashi, 1935, p. 154; Resser, 1942, p. 35.; Robison, 1964a, p. 538.

[?] *Marjumia tetonensis* Miller, 1936, p. 33, pl. 8, fig. 21 [only].

[?] *Kootenia tetonensis* (Miller) Resser 1937, p. 15.

[?]*Olenoides incertus* Shaw, 1956, p. 145.

[?]*Olenoides* cf. *incertus* Shaw, (Lochman and Hu 1960), p. 827, pl. 100, fig. 41.

Occurrence - Pika Formation, Chaba River (GSC locs. 72742-44).

Material - 44 cranidia and 28 pygidia.

Description - Convex, subrectangular, unfurrowed glabella expands slightly forward. Preglabellar furrow is faint and gently curved. Axial furrows are straight and well impressed. Occipital furrow is slightly curved. Occipital ring sub - triangular, with a short medial spine. Short, crescentic palpebral lobes are located slightly anterior of the glabellar midlength, with a faint, oblique, palpebral ridge. Pits present in axial furrows opposite palpebral ridge. Facial sutures slightly convergent up to the anterior corner of the glabella where they converge rapidly, producing a frontal area that is very short. Preglabellar field absent, and anterior border short and slightly convex. Fixed cheeks are convex and sloping away from the glabella posteriorly. Surface of exoskeleton is smooth.

Hypostome is sub-rectangular in outline and fused to the rostral plate. Median body is divided into long, strongly convex anterior lobe and shorter, flatter crescentic posterior lobe. Lobes are separated by shallow, narrow median furrow. Posterior margin is slightly upturned from narrow flat border. Hypostome and rostral plate carry prosopon of terrace ridges.

Pygidium is semi-circular in outline with width to length ratio approximately 4:3. Long, cylindrical axis terminates close to posterior pygidial margin and is divided into 3 axial rings and a terminal piece by sub-transverse ring furrows. Three pairs of broad, well impressed pleural furrows with two pairs of faint, diagonal, interpleural grooves. Border is narrow. Four pairs of long marginal spines, all of roughly equal length and curving backwards except the posteriormost pair which are straight and parallel. Spines circular in cross section.

Discussion - *Olenoides pugio* has a pygidium with four pairs of marginal spines of approximately equal length and four rings (as opposed to three that the Pika specimens apparently possess) on the axis with a long, subdivided, terminal piece. The interpleural furrows are more deeply impressed than those on specimens from the Pika, but otherwise the

pygidia are similar (Resser 1937; Robison 1964a, pl. 84 , figs. 6, 17). *Olenoides incertus* Shaw (1956) was based on a single pygidium from the Death Canyon Formation of Wyoming that Miller (1936, pl. 8, fig. 21) had assigned to *Marjumia tetonensis*. Lochman and Hu (1960) found a single fragmentary dorypygid cranidium from the same area as Miller and assigned it to *Olenoides* cf. *incertus* Shaw. The pygidium referred to by Shaw has a similar axis to the Pika species with three axial rings and a long divided terminal piece. It also possesses four pairs of spines which, although incomplete, appear to be equally robust and therefore possibly of equal length. The interpleural furrows are relatively narrow, although slightly more deeply impressed than those illustrated here. The affiliation of *O. incertus* and *cf. O. incertus* is, however, tentative due to the paucity of well illustrated material for *O. incertus*. *O. expansus* (Walcott 1884; Robison 1964a, pl. 83, fig. 12) has four pairs of spines, but the third pair is longer and more robust than the others and the fourth pair is greatly reduced; additionally, the pygidial furrows are deeper. Other species of *Olenoides* from the Great Basin (e.g. *O. wasatchensis* Hall and Whitfield 1861 [Palmer 1954, pl. 14, figs. 6, 8] and *O. nevadensis* Meek [Palmer 1954, pl. 14, fig. 9] and *O. decorus* [Robison 1964a, pl. 84, figs. 2, 3, 14, *O. inflatus* [Robison 1964a, pl. 84, figs. 7 - 9], *O. marjumensis* [Robison 1964a, pl. 84, figs. 4, 5] and *O. superbus* [Robison 1964a, pl. 84, fig. 11]) have more pygidial spines. The pygidium of *O. ternus* (Robison 1988, pl. 16, figs. 16-18) has a waisted axis and three pairs of marginal spines. *O. optimus* Lazarenko (1982, pl. 52, figs. 13, 16, pl. 55, fig. 9, pl. 56, figs. 10, 14, pl. 59, figs. 12, 12a) has four pairs of pygidial spines, with the third pair being longer, and a glabella with deeply impressed furrows.

Family Marjumiidae Kobayashi 1935

Remarks The Marjumiidae are a generalised group of trilobites and was regarded as the ancestor of the Crepicephalidae and Tricrepicephalidae by Robison (1964a). As such, it is likely to be paraphyletic. Robison's (1988) revised diagnosis does not include any obvious synapomorphic characters that might be used to define the Marjumiidae, although the rostral plate morphology of *Marjumia* (Robison 1964a, pl. 87, fig. 11) is unusual in that the hypostomal sutures converge sharply backwards medially to produce a small, sub-triangular projection of the posterior margin. However, a cladistic revision of the Marjumiidae and related taxa would be a major undertaking and is beyond the scope of this thesis.

Arapahoia and *Talbotina* were removed from the Marjumiidae by Westrop (1992) and Pratt (1992) transferred *Pearylandia* to the Llanoaspidae, thereby reducing the family to: *Marjumia* Walcott, 1916 (=*Modocia* Walcott 1924), *Ithyektyphus* Shaw, 1956, and *Syspacheilus*, Resser 1938, emend. Lochman and Hu 1961. The genus *Glyphopeltis* Deiss (1938, pl. 17, figs. 34, 35) is based on poorly illustrated, flattened specimens and is possibly a synonym of *Marjumia.*

Genus *Marjumia* Walcott 1916

Type species - *Marjumia typa* Walcott (1916) from the Upper Cambrian Marjum Formation in Utah (By original designation).

Diagnosis - A genus of the Marjumiidae with a short, broad pygidium that possesses a variably spinose pygidial margin and two to four axial rings.

Discussion - In previous work (e.g. Robison 1964a), *Marjumia* was separated from the genus *Modocia* primarily on the presence of marginal spines on the pygidium. Pratt (1992, p.

60) suggested that this distinction may be artificial, and further examination of the two genera, with additional data from *Marjumia bagginsi* sp. nov. shows that spinosity cannot be used to separate these genera. *M. bagginsi* has a variably spinose pygidium (see pl. 2, figs. 12, 15, 17, 18) ranging from a single lateral spine to a multi-spined or "scalloped" margin. Comparison of the multi-spined *Marjumia typa* (Walcott 1916, pl. 65, figs. 4a-b), the singly-spined *Marjumia callas* (Walcott 1916, pl. 65, figs. 3a-b), the two morphologies of *Marjumia bagginsi* (pl. 2, figs. 12, 17) and the smooth margined *Marjumia* cf. *transversa* (pl. 1, figs. 10-12) shows that the pygidia of these species from both genera span a continuous spectrum from spinose to non-spinose. Moreover, the smooth pygidial margins of species previously assigned to *Modocia* (e.g. *M. laevinucha* [Robison 1964a, pl. 87, figs. 5-10] and M. transversa [Palmer 1968, pl. 5, figs. 1-5]) are also shared with other marjumiids such as *Syspacheilus* (Robison 1988, pl. 20, figs. 12, 13), as well as with most Ptychopariina. Thus, the key feature in the diagnosis of *Modocia* may be interpreted as being plesiomorphic, rather than apomorphic. *Modocia* is therefore suppressed as a junior synonym of *Marjumia.*

Syspacheilus (emend. Lochman and Hu 1961, pl. 26, figs. 1-48, pl. 27, figs. 1-30) is similar to *Marjumia*, but has short or blunt genal spines and a narrower pygidium. The poorly known genus *Ithyektyphus* Shaw (Lochman and Hu 1960, pl. 100, figs. 15-27) has a subtriangular pygidium and straight marginal spines. *Pearylandia* (Robison 1988, pl. 18, fig. 1-11) has anteriorly placed palpebral lobes, a short genal spine and a relatively short pygidium with a median indentation.

Marjumia cf. *transversa* (Palmer)

(Pl. 1, figs. 7-13)

Modocia transversa Palmer 1968, p. 65, pl. 5, figs. 1-5

Occurrence - Pika Formation, Chaba River (GSC locs. 72728, 29,30.

Description - Convex, rounded, tapering glabella has well rounded anterior margin. Axial and preglabellar furrows are well defined. Occipital furrows are straight. Occipital ring is smooth and crescentic. Glabella is somewhat effaced, with oblique 1s furrow, and transverse 2s and 3s furrows evident on some specimens. Palpebral lobes are short and crescentic and located in front of glabellar midlength. Palpebral ridges are faint and curved. Fixed cheeks are slightly convex and slope down away from the glabella. Facial sutures are anteriorly divergent producing a broad (trans.) frontal area that is separated into a short, downsloping preglabellar field and a longer, rounded and convex anterior border by a gently curved anterior border furrow. Surface of cranidium is smooth to slightly granulose, with anastomosing caecal ridges occasionally present on preglabellar field and palpebral lobes.

Free cheek is generally crescentic and possesses a moderately long genal spineand a broad convex border. Some specimens show anastomosing caecal marks.

Pygidium is semicircular to alaform in outline. Anterior margin is slightly curved anteriorly. Broad stubby axis occupies approximately three quarters of pygidial length. Axis is divided into two to three axial rings and a broad terminal piece. Three pairs of pleural furrows and two pairs of interpleural furrows occur on the pleural field, and the anteriormost of the forrows is most deeply impressed. Margin lacks spines.

Discussion - As Robison (1964) and other authors have stated, species of the Marjumiidae require associated cranidia and pygidia to be identified with confidence. *Marjumia oweni* (Walcott 1924, pl. 12, fig. 7) appears to possess wider fixed cheeks and a longer preglabellar field than than *Marjumia* cf. *transversa*. *Marjumia brevispina* (Robison 1964a pl. 87, figs. 11-19) possesses a short genal spine and four axial rings on the pygidium. *Marjumia laevinucha* (Robison 1964a, pl. 87, figs. 5-10) has longer palpebral lobes, a longer preglabellar field and a more strongly curved anterior border. *M*arjumia *nuchaspina* (Robison 1964a, pl. 88, figs. 1-6) possesses an occipital spine. *Marjumia typicalis* (Resser; Robison 1964a, pl. 87, figs. 20, 21) possesses unusual thoracic segment development and can not be properly compared to *M.*

cf. *transversa*. *Marjumia planata* (Robison 1988, pl. 21, figs. 1-9) is similar to *M.* cf. *transversa*, but its palpebral lobes are situated much more posteriorly. *Marjumia transversa* (Palmer 1968, pl. 5, figs. 1-5) differs from *M.* cf. *transversa* on the basis of a slightly shorter pygidium and more posteriorly located palpebral lobes.

Marjumia bagginsi sp. nov.

Holotype - A pygidium from the Pika Formation in the southern Canadian Rocky Mountains, illustrated here as plate 2, figure 12.

Etymology - *Marjumia bagginsi* is named for Bilbo Baggins, the hero of The Hobbit by J.R.R. Tolkien, and my family's nickname for my sister Kathryn.

Material - 119 cranidia, 25 pygidia and 1 hypostome.

Occurrence - Pika Formation, Windy Point (GSC loc. 52576) and Roche Miette (loc. RM-03,04).

Diagnosis - A species of *Marjumia* with two axial rings on the pygidium and variable development of spinosity ranging from a single pair of short lateral spines to a scalloped margin.

Description - Glabella is convex, straight - sided and anteriorly rounded. Axial and preglabellar furrows are well developed. Occipital furrow is straight and well impressed and the occipitial ring is smooth and crescentic. Two to three glabellar furrows are visible. Palpebral lobes are short and crescentic and are located at or anterior of glabellar midlength. Palpebral ridges are faint and oblique. Fixed cheeks are narrow, slightly convex and slope

away from the glabella. Facial sutures are slightly divergent anteriorly, producing a short, broad frontal area that is divided into a short, flat preglabellar field and a longer, upturned anterior border by a slightly curved anterior border furrow. Surface of the test is slightly granulose.

Hypostome is subelliptical in outline. Median body is divided into a long, convex anterior lobe and a narrow, crescentic posterior lobe by a well defined median furrow. Border is narrow and convex. The anterior portion of the single specimen is damaged.

Pygidium is alaform in outline. Broad, stubby axis composed of two axial rings and a short divided terminal piece. Three pleural furrows and two interpleural grooves are present, with the anteriormost furrow being the most deeply impressed. The margin is variable, possessing a small lateral spine (pl. 2, figs. 12, 15) or scalloped (pl.2, figs. 17,18).

Discussion - The cranidia of *Marjumia bagginsi* resemble most other cranidia assigned to *Marjumia* (e.g. *M. callas* Walcott; Robison 1964a, pl. 86, figs 17-21). The marginal scalloping or spinosity of the pygidium separates *M. bagginsi* from all the smooth margined species prevously assigned to *Modocia* (eg. *Marjumia oweni* (Walcott 1924 pl. 12, fig. 7), *M. laevinucha* (Robison 1964a, pl. 87, figs. 5-10), (*M. transversa* Palmer 1968, pl.5, figs 1-5) etc.). *Marjumia typa* Walcott (Robison 1964, pl. 87. figs. 1-4) has three pairs of long pygidial spines. *Marjumia callas* Walcott (Robison 1964a, pl. 86, figs. 17-21) is similar to the single spine specimens of *M. bagginsi* but its spine is longer, as is the pygidium.

There is a gradation between the single-spined and multi-spined morphologies and they are found together in collections with a single cranidial morph. For this reason, a broad species concept is adopted here.

Marjumia? sp.

(Pl. 2, figs. 19, 20)

Occurrence - Pika Formation, Chaba River (GSC locs. 72742-44).

Material - 29 cranidia and 4 pygidia.

Description - Glabella is convex and quadrate, and slightly anteriorly rounded. Glabella is unfurrowed. Fixed cheeks are slightly convex and sloping gently away from the glabella. Palpebral lobes are long and crescentic and located at the glabellar midlength. Palpebral ridges nearly obsolete. Facial sutures are anteriorly divergent. Preglabellar field and upturned border are subequal in length and separated by a well developed anterior border furrow that shallows medially. Surface of test is slightly granulose.

Pygidium is semicircular in outline. Axis is broad with three faint rings and a short terminal piece. At least two pairs of furrows and interpleural grooves are present, with the anteriormost being deepest. Margin is not spinose. Surface of test is granulose.

Discussion - The cranidia are comparable to those assigned to *Marjumia* cf. *transversa* (Pl. 1, figs. 7-9), but possess a glabella that is less rounded anteriorly and wider fixed cheeks. The glabella is less convex than those of *M.* cf. *transversa* and other species. The single pygidium is similar in outline and axial morphology to other smooth margined *Marjumia*. The granulosity and median shallowing of the anterior border furrow are the only distinguishing characteristics of *M.*? sp. and due to the low number of specimens, particularly pygidia, and relatively poor of preservation, this taxon is left unassigned.

Family **Menomoniidae** Walcott 1916

Genus *Bolaspidella* Resser 1937

Type species - *Ptychoparia housensis* Walcott 1886, from the Wheeler Shale of Utah (by original designation).

Bolaspidella resseri (Miller 1936)

(Pl. 2, figs. 1-3)

Bolaspis? resseri Miller, 1936, p. 27, pl. 8, fig. 38.

Bolaspidella resseri (Miller), Resser 1937, p. 3.

Occurrence - Pika Formation, Chaba River (GSC loc. 72732), Windy Point (52577-77b), Death Canyon Limestone, Wyoming (Lochman and Hu 1960).

Material - 44, mostly poorly preserved, cranidia.

Diagnosis - A species of *Bolaspidella* with an anteriorly rounded to slightly truncate and gently tapered glabella with well defined glabellar furrows, a non-spinose occipital ring and a preglabellar field longer than the anterior border.

Description - Cranidium is small, convex, and subrectangular in outline. Glabella is convex, anteriorly tapered and occupies approximately seven tenths of cranidial length. Glabella varies from anteriorly rounded to slightly truncate (see pl. 2, figs. 1,3). Axial and preglabellar furrows are well impressed. Occipital furrow is variably impressed, but usually deep and occipital ring is smooth. Three pairs of shallow glabellar furrows are present; 1s and 2s are oblique, 3s is transverse. Palpebral lobes are short, crescentic, and sharply upturned from the fixed cheek. Palpebral lobes are located opposite or slightly posterior of glabellar midlength.

Palpebral ridges are transverse and slightly anteriorly curved. Facial sutures are nearly parallel opposite palpebral lobes, sharply divergent posteriorly, and slightly convergent anteriorly. Frontal area is short and divided into flat or slightly downsloping preglabellar field and shorter, upturned anterior border. Anterior border furrow is straight. Anterior border is longest axially and shortened laterally. Fixed cheeks are convex and inflated, and approximately equal in width to the glabella. Surface of fixed cheeks is granulose.

Discussion - *Bolaspidella resseri* was questionably described by Miller (1936, pl. 8, fig. 39) as *Bolaspis resseri* and subsequently assigned to *Bolaspidella* by Resser (1937) without reillustration. The figure in Miller (1936) is of a small slab with a number of cranidia. The cranidial outline, shape of the glabella, glabellar furrows, position of the palpebral lobes and frontal area are virtually identical to the specimens from the Pika Formation. Miller also described coarse granules on the surface. *Bolaspidella contracta* Robison (1964a, pl. 89, figs. 14-16) is most similar to *B. resseri*, and lacks an occipital spine, a feature common to most species. *B. contracta* has an apparently narrower, straight-sided glabella without furrows, and, in the larger specimens, the preglabellar field is slightly shorter. However, *B. contracta* is known from only three illustrated specimens (Robison 1964, pl. 89, figs. 14-16) and may prove to be a synonym of *B. resseri*. Figure 21 shows a scatter plot of cranidial length versus preglabellar field length for *B. resseri* and the illustrated specimens of *B. contracta*. Of the three specimens of *B. contracta* illustrated by Robison, two plot with those of *B. resseri*, while the largest specimen is a distinct outlier. More data will be required to characterise these species adequately. *B. housensis* (Walcott; Robison 1964a, pl. 88, figs. 16-21 and pl. 89, figs. 1-11) possesses an occipital spine and a more rectangular glabella, as does *B. drumensis* (Robison 1964a, pl. 88, figs. 7-15). *B.? tuberculata* (Rasetti 1963, pl. 66, figs. 16-20) has coarser granules, a shorter, more triangular glabella, a more sharply curved anterior border and a longer occipital ring. *B. interrupta* (Rasetti 1963, pl. 68, figs. 6-8) has a more triangular

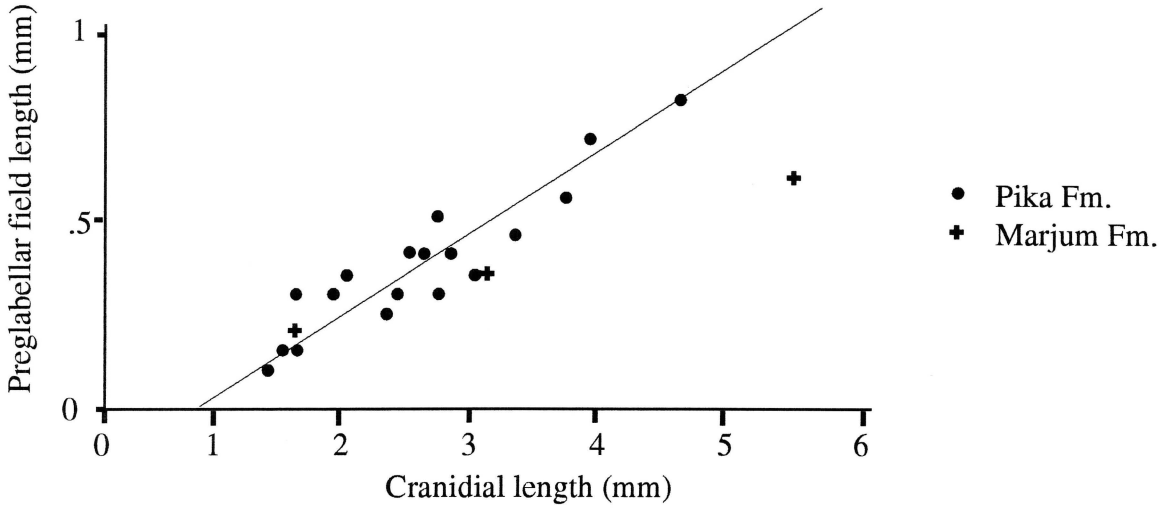


Figure 20 - Bivariate scatter plot of preglabellar field length vs. cranidial length for *Bolaspidella* from the Pika and Marjum Fms.Reduced major axis regression for Pika material :PGF length =.19*cranidial length -.096, r-squared= .857, standard error of slope = .019.

glabella, more posteriorly located palpebral lobes, and facial sutures that are slightly divergent anteriorly.

Genus *Knechtelia* Lochmann 1950

Type species - *Knechtelia ann* Lochman 1950 from the Upper Cambrian Pilgrim Formation of Montana (by original designation).

Diagnosis - A genus of menomoniid with divergent posterior sutures, producing a cranidium that is sub-trapezoidal in outline. Posterior fixed cheeks narrow. Cranidium convex and anteriorly arched.

Discussion - *Knechtelia* was initially described from poor material from Wyoming (Lochman 1950, pl. 51, figs. 1-3), but new silicified specimens from the Pika Formation allow a more complete evaluation of this genus to be made. The trapezoidal outline of the cranidium of *Knechtelia* is unique among menomoniid genera.

Menomonia Walcott (1916 pl. 26, figs. 4, 4a-d; Pratt 1992, pl. 29, figs. 1-12) possesses a glabella that is wider and more tapered than the glabella of *Knechtelia*. Additionally, the facial sutures of *Menomonia* diverge rapidly posterior of the palpebral lobes and are nearly parallel anteriorly, in contrast to the nearly straight, anteriorly convergent sutures of *Knechtelia*. *Bolaspidella* (Walcott 1886; Robison 1964a, pl. 88, figs. 16 - 21) possesses a subrectangular glabella similar to *Knechtelia*, but its fixed cheeks are much broader (trans.) and the anterior border is very weakly arched. Also, the posterior branches of the facial suture of *Bolaspidella* are sharply divergent. The smaller illustrated specimens of *B. housensis* (Robison 1964a, pl. 89, figs. 3-5) possess weakly anteriorly divergent facial sutures that are similar to those of *Knechtelia*, suggesting that *Knechtelia* may be paedomorphic. *Dresbachia* (Walcott 1916, pl. 25, figs. 5, 5a-c, Rasetti 1965, pl. 8, figs. 1-4) has a triangular glabella, its palpebral lobes are

located directly anterior of the glabella, lacks an anterior border, and has posterior fixed cheeks that are several times wider than the glabella.

Josina (Lochman and Hu 1960, pl.100, figs. 28-35) from older rocks in Wyoming was described from a small number of incomplete cranidia. Examination of the types (USNM 138190, 138191a-e) showed that its trapezoidal outline and arched anterior border are very similar to *Knechtelia*. The two genera are apparently identical and *Josina* is, therefore, suppressed as a junior synonym of *Knechtelia*.

Knechtelia festiva (Lochman and Hu 1960)

(Pl. 4, fig. 13-18)

Josina festiva Lochman and Hu 1960, p. 830, pl. 100, figs. 28-35

Occurrence - Pika Formation, Chaba River (GSC locs. 72736, 38,40,41), Death Canyon Limestone, Wyoming (Lochman and Hu 1960).

Material - 56 silicified cranidia.

Description - Cranidium is small, trapezoidal in outline and highly convex. Glabella is convex, elongate and subrectangular in outline, with a slight anterior taper. Axial furrow is broad but shallow and the preglabellar furrow is not apparent. Occipital furrow is narrow and deeply impressed. Glabella externally unfurrowed. Facial sutures are nearly straight and anteriorly convergent at approximately 70 degrees. Palpebral lobes are small, crescentic and located well anterior of glabellar midpoint. Faint palpebral ridges present. Fixed cheeks are broadest (trans.) posteriorly where they are slightly convex and then slope rapidly away from the glabella. Anterior fixed cheeks are narrower and almost flat. Preglabellar field is short, flat sagitally and sloping outwards laterally. Anterior border is short, sharply upturned from the

preglabellar field, and strongly arched when viewed frontally (see fig). Posterior border furrow is well impressed and broader (exsag.) than occipital furrow. Posterior margin upturned towards glabella and flattening laterally. Surface of fixed cheeks is coarsely granulose.

Discussion - *Knechtelia festiva* was first described by Lochmann and Hu (1960, pl. 100, figs. 28 - 35) from poorly preserved material from Wyoming. Examination of the types revealed that none of the cranidia is complete and that the posterior fixed cheeks were damaged on virtually all specimens, thereby obscuring the trapezoidal outline of the cranidium. The glabella, palpebral lobes, frontal area and anterior facial suture were well displayed, and were identical to the specimens from the Pika Formation. Knechtelia ann Lochman 1950 (pl. 51, figs. 1-3), differs from K. festiva by lacking granulosity on the fixed cheeks and by possessing a bullet-shaped rather than sub-rectangular glabella.

A few specimens of *Knechtelia* from in the Pika Formation (see pl. 4, fig. 18) are somewht shorter and wider than most other specimens, but (Fig. 20), a scatter plot of width across palpebral lobes/maximum width versus cranidial length indicates that the amount of variability is minor.

Order and Family uncertain

Genus *Glyphaspis* Poulsen 1927

Type species - *Asaphiscus capella* Walcott 1916 from the Middle Cambrian Wolsey Shale of Montana (by original designation).

Diagnosis - Isopygous "ptychopariid". Cranidium with anteriorly diverging sutures producing broad (trans.) frontal area. Palpebral lobes relatively long, crescentic, and

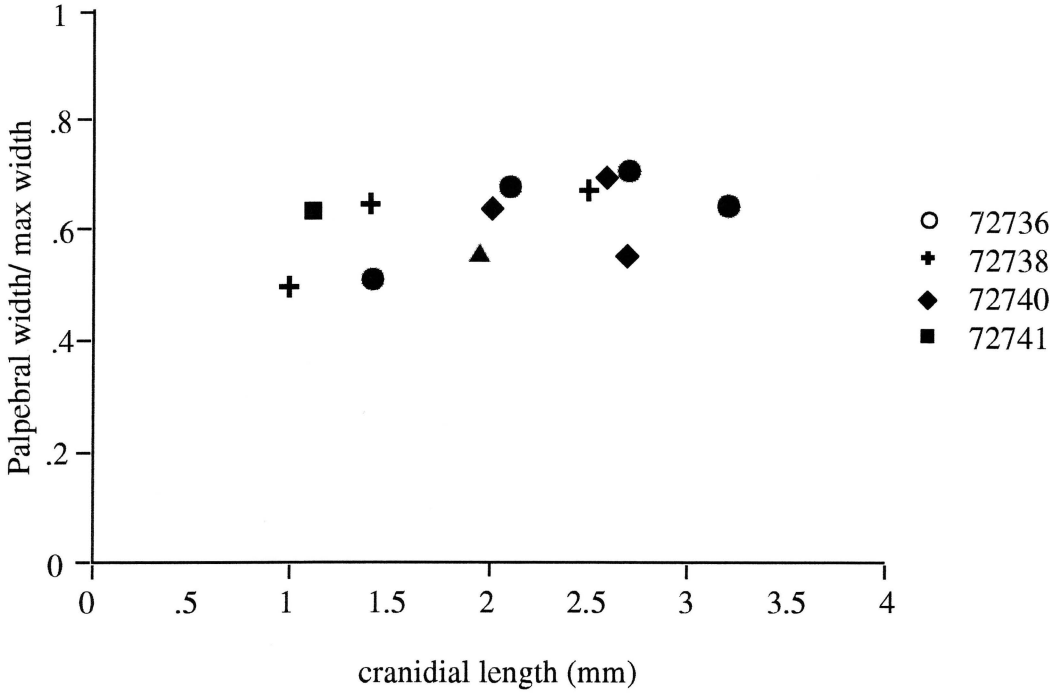


Figure 22 - Bivariate scatter plot of palpebral width/ max width vs. cranidial length for *Knechtelia festiva* from the Pika Formation with the symbols representing different collections.

posteriorly located. Posterior branches of fixed cheeks abruptly divergent. Rostral plate short (sag.) and broad (trans.) with concave, v-shaped connective sutures. Free cheeks with relatively long genal spines.

Large pygidium with broad doublure. Pleural furrows well defined and extending onto border. Shallow interpleural grooves.

Discussion

Glyphaspis was previously assigned to the Anomocaridae (Lochmann and Hu 1960). However, all members of this family are characterised by median sutures (Fortey and Chatterton 1988), whereas new data from the Pika Formation indicates that *Glyphaspis* possesses a rostral plate (pl. 4, figs. 6,8). Also, cranidia of typical anomocariids, such as *Anomocare* and *Anomocariina* (Westerg_rd 1949, pl. 3, figs. 1, 13-14, pl. 4, fig. 2) differ from *Glyphaspis* in possessing much wider palpebral areas and bacculae on the cheeks. In their cladistic re-evaluation of the of the suborder Asaphina, Fortey and Chatterton (1988) emphasised the fundamental distinction between taxa with rostral plates and taxa with median sutures and restricted Asaphina to the latter. Accordingly, *Glyphaspis* is removed from both the Anomocariidae and the Asaphina.

Schwimmer (1989) placed *Glyphaspis* in the Asaphiscidae, but this hypothesis is difficult to evaluate because asaphiscids (e.g. *Asaphiscus gregarius* and *A. paula* (Schwimmer, 1989, pl. 3, figs. 10-12, 15,16)) are usually strongly effaced. However, there do not appear to be any synapomorphic characters that unite *Glyphaspis* and *Asaphiscus*, and, for this reason, Schwimmer's suggestion is not followed here.

Glyphaspis and the Chinese genus *Proasaphiscus* (Chang and Jell 1987, pls. 58-60) are similar, particularly in the shape and furrowing of the pygidium, but *Proasaphiscus* is not isopygous and possesses a quadrate glabella. The rostral plate of

Glyphaspis closely resembles the rostral plates of *Elrathia* (Robison 1964a, pl.85, figs. 6, 14). The significance of this is uncertain because rostral plates are known from relatively few Cambrian trilobites. However, *Elrathia* is micropygous and has a short anterior border, smaller palpebral lobes, and a less divergent facial suture. The suprageneric affiliation of *Glyphaspis* is, therefore, uncertain.

The genus *Americare* was erected by Lochmann and Hu (1960, pl. 100, figs. 42-57) for a *Glyphaspis* - like trilobite that possesses a facial suture that diverges anteriorly more strongly than *Glyphaspis*. The only other distinguishing feature is degree of effacement of pleural furrows on the pygidium. These are only minor features and therefore *Americare* is synonymised with *Glyphaspis*.

Hu (1971 pl. 12, figs. 16-24) established a new genus, *Iohomia* which he claimed exhibited sexual dimorphism. The illustrated "female" specimens (figs. 16, 17, 20, 23, 24) are closely comparable and undoubtedly congeneric with *Glyphaspis*. *Iohomia* should, therefore be restricted to " male " specimens (figs. 18-19, 20-22, 25-30) which have a longer, subtriangular anterior border, a median pit in the preglabellar field, and a pygidium that is sub-triangular, rather than semi-circular.

Glyphaspis tetonensis (Lochman and Hu 1960)

(Pl. 4, figs. 1-12, pl. 5, figs. 1-10)

Americare tetonensis Lochman and Hu 1960, p. 828, pl. 100, figs. 42-57.

Diagnosis - A species of *Glyphaspis* with relatively short palpebral lobes, a long pygidial axis with up to eight axial rings, and a shallow median indentation on the pygidium.

Occurrence - Pika Formation, Chaba River (GSC locs. 72736-72741). Death Canyon Limestone, Wyoming (Lochman and Hu 1960).

Description - Convex, forward tapering glabella occupies approximately two thirds of total cranidial length; is outlined by well defined axial furrows and variably effaced preglabellar furrow. Occipital furrow is straight and well defined. Oblique 1s glabellar furrow is commonly expressed while transverse 2s and 3s furrows are preserved on a few silicified individuals (see pl.5, fig.2). Long, crescentic palpebral lobes are located posterior of glabellar midpoint and approximately 1/3 glabellar width from axial furrow. Facial sutures strongly divergent anteriorly, producing wide (trans.) frontal area. Flat preglabellar field and upturned anterior border are subequal in length and separated by shallow anterior border furrow. Posterior facial sutures are strongly divergent.

Free cheek has long tapering genal spine and smooth convex border. Centre of free cheek is covered with anastomosing caecal marks.

Hypostome has long median body divided into convex, oval anterior lobe and crescentic posterior lobe. Median furrows deeply incised and nearly meeting. Lateral border narrow, convex and covered with terrace lines.

Rostral plate is broad (trans.) and short (sag.) with triangular, concave connective sutures.

Pygidium is sub-elliptical to sub-polygonal in outline, with a width to length ratio between 2:1 and 3:2. Axis is narrow, tapering, and partially effaced, and has up to eight axial rings (see Pl. 5, fig. 1) and a rounded terminal piece. Pleural field has six or seven posteriorly curving interpleural furrows, depending on effacement. Doublure is broad and marked on dorsal surface by a faint paradoublural furrow. Posterior margin is medially flattened or indented.

Discussion - Examination and measurement of the types of *G. tetonensis* from Wyoming shows that they are indistinguishable from the specimens from Alberta (see figs. 22, 23). *Glyphaspis tetonensis* is separable from *G. capella* (Walcott 1916, pl. 59, figs. 2, 2a-c) and *G.* cf. *capella* Schwimmer (1989 pl.3, figs.13, 14, 17, 18) by possession of shorter palpebral lobes and a shorter preglabellar field. The poorly illustrated *G. perconcava* Poulsen (1927 pl. 17, figs. 3, 4) possesses a shorter pygidial axis and the figured cranidium is an immature individual and can not be evaluated fully. *G. parkensis* Rasetti (1951 pl. 34, figs. 5-7) has only 6 axial rings and a shorter axis, and more strongly developed eye ridges. *G. cf. parkensis* Rasetti (Hu 1971 pl. 11, figs. 1-30) is similar to *G. tetonensis* but appears to have longer palpebral lobes in addition to a relatively longer pygidium with a shorter axis.

G. tetonensis exhibits considerable intraspecific variability. The glabella varies from bullet shaped (Pl. 5, fig. 3) to tapered (Pl. 5, fig. 1), with the amount of taper increasing with increasing size. The palpebral lobes are longer and more curved in juveniles and gradually shrink and move posteriorly (see Pl. 4, figs. 1-3,9 and pl. 5, figs. 2, 3). The pygidia vary in outline from semi-circular (Pl. 4, fig. 1) to sub-elliptical (pl. 4, fig. 4) and sub-pentagonal (Pl. 5, fig. 10). The anterior margin of the pygidium becomes straighter with increasing size but the polygonal aspect of some specimens (Pl. 5, fig. 10) is not size related. Smaller hypostomes are quadrate with circular anterior lobes and become more rectangular with oval anterior lobes with increasing size (Pl. 4, figs. 9-11, pl. 5, fig. 8). Despite the variability described above, certain features remain constant; in particular the ratio of glabellar length to cranidial length is always 2:3 in the adult specimens.

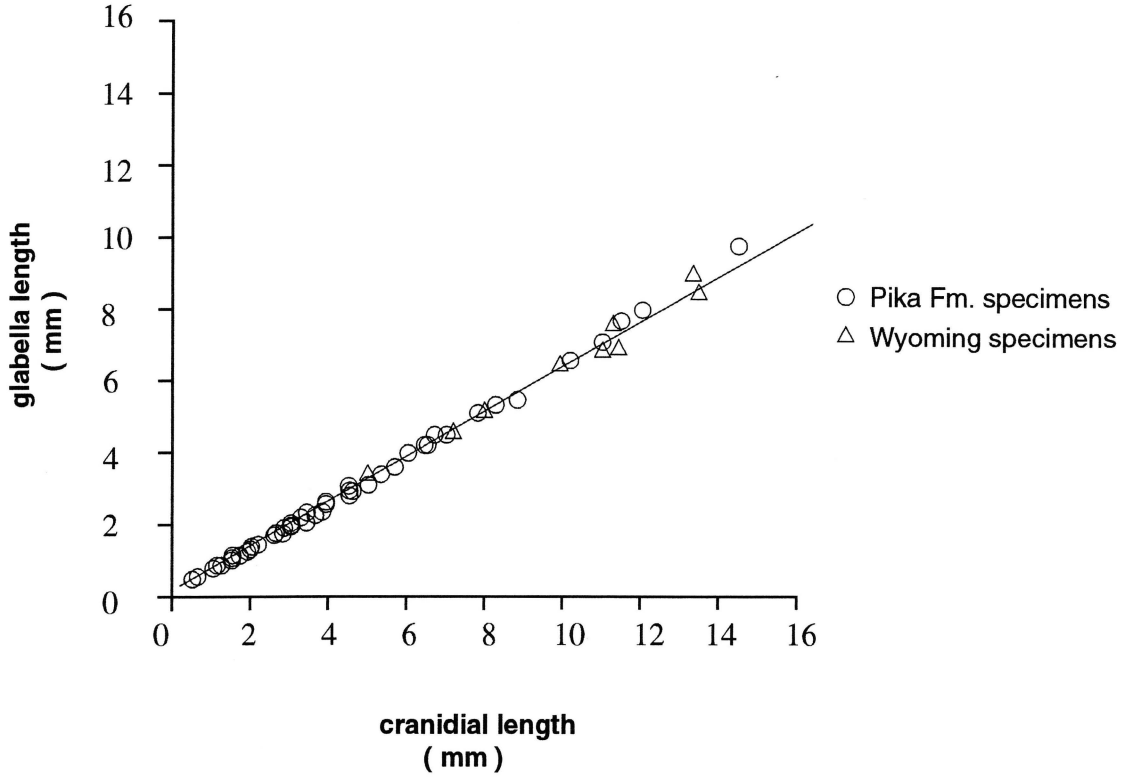


Figure 22 - Bivariate scatter plot of glabellar length vs. cranidial length for *Glyphaspis tetonensis* from the Pika Formation (circles) and Wyoming (triangles). Reduced major axis regression: glabella length = .646 cranidial length +.060, n=73, r-squared=.997 , standard error of slope= .004.

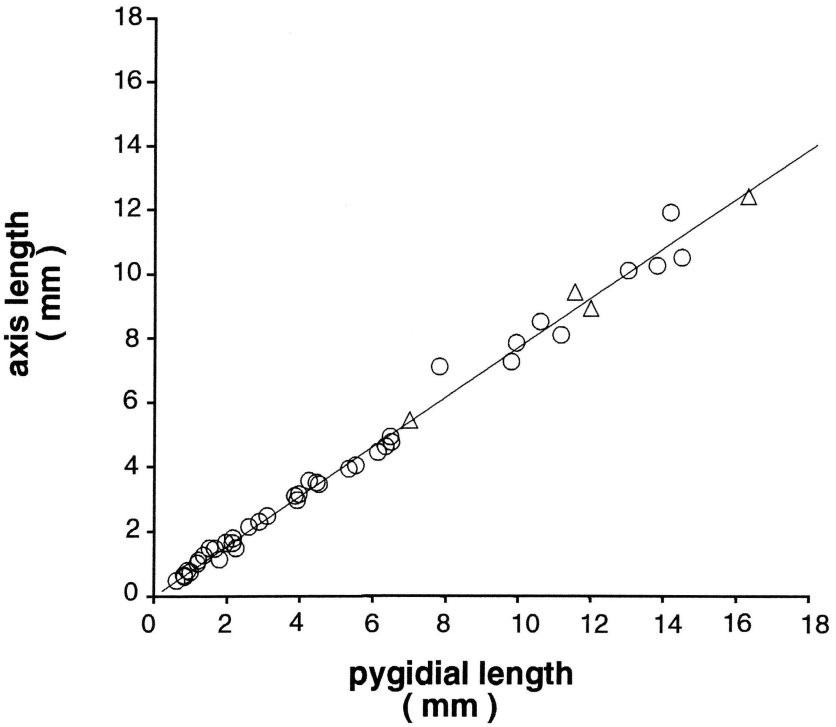


Figure 23 - Bivariate scatter plot of axis length vs. pygidial length for *Glyphaspis tetonensis* from the Pika Formation (circles) and Wyoming (triangles). Reduced major axis regression: Axis length = .764 Pygidial length +.128, n=51, r squared = .983, standard error of slope =.009)

Glyphaspis sp. 1

(Pl. 5, figs. 11, 12)

Occurrence - Pika Formation, Chaba River (GSC loc. 72743).

Material - One nearly complete cranidium and 5 fragmentary cranidia.

Description - Glabella is convex, straight sided, anteriorly tapering and rounded. Axial furrow is well impressed, preglabellar furrow is not present. Occipital furrow is shallow. Occipital ring is short, smooth and crescentic. No glabellar furrows are visible. Palpebral lobes are short, crescentic and located posterior of the glabellar midpoint. Palpebral area of fixed cheek is very narrow (trans.). Facial sutures are strongly divergent anteriorly and posteriorly, giving the cranidium a " waisted " appearance. The broad frontal area is divided into a short, flat preglabellar field and a longer, upturned anterior border. Anterior border furrow is shallow. Surface of cranidium smooth.

Discussion - *Glyphaspis* sp. 1 is similar to *G. tetonensis* from lower down in the same section, but *G. tetonensis* possesses broader (trans.) fixed cheeks and the preglabellar furrow is well impressed in all specimens. Additionally, the cranidial furrows are well impressed on virtually all specimens of *G. tetonensis*, while *G.* sp. 1 has very shallow furrows. *G.* sp. 1 may represent a new species, but,because of the limited number of specimens available, open nomenclature is used.

Glyphaspis sp.2

(Pl. 2, figs. 9, 10)

Occurrence - Pika Formation, Roche Miette (locs. RM-05/8), Windy Point (GSC locs. 52577,52577b).

Material - 700 cranidia and 39 pygidia; specimens are mostly poorly preserved on weathered bedding surfaces.

Description - Glabella is convex and forward tapering and outlined by weakly defined axial and preglabellar furrows. Oblique 1s furrow is well defined. Occipital ring is short and crescentic. Palpebral lobes are short, crescentic and anteriorly placed. Facial sutures are rapidly divergent anteriorly producing a broad frontal area divided subequally into a slightly downsloping preglabellar field and an upsloping anterior border.

Pygidium is large and semi - circular in outline. Axis broad and apparently formed of four axial rings and a short terminal piece. Five pairs of pleural furrows and interpleural grooves, extending nearly to the margin, are visible. Margin smooth and slightly medially indented.

Discussion - Almost all available specimens of *Glyphaspis* sp. 2 are poorly preserved on weathered bedding surfaces; the best cranidium and pygidium are illustrated here (Pl. 2, figs. 9, 10). Cranidia are indistinguishable from those of *G. tetonensis* (Pl. 4, figs. 1-4, 9 and Pl. 5, figs. 2,3) and *G. capella* (Walcott 1916, pl. 59, figs. 2a-c). The axis of the pygidium of *G.* sp. 2 is broader than those of *G. tetonensis, G. capella* and *G. perconcava* Poulsen (1927, pl. 17, figs. 3, 4) and possesses only four axial rings where the other species possess six or seven. The Pika specimens may represent a new species, but, in view o ftheir poorly preserved nature, they are placed in open nomenclature.

Glyphaspis? cf. *curticei* Resser 1938

(Pl. 3, figs. 1-3,6)

Amecephalina curticei Resser 1938, p. 38, pl. 8, figs. 59,60.

Occurrence - Chaba River (GSC locs. 72731/32), Pika Formation, Alberta.

Material - 19 cranidia and 15 pygidia, many fragmentary.

Description - Cranidium is relatively flat and quadrate in outline. Convex and frontally rounded glabella is slightly tapered anteriorly. Axial and preglabellar furrows are well impressed. 1s glabellar furrow is present on all specimens, 2s is faintly impressed on some specimens. Occipital furrow is broad and shallow, and occipital ring is short and crescentic. Short, crescentic palpebral lobes are approximately located opposite glabellar midlength, more than half of the glabellar width from the axial furrow. Fixed cheeks are broad and convex. Palpebral ridges are faint and oblique. Facial sutures are anteriorly divergent, producing a broad frontal area divided into a long, concave preglabellar field and a shorter, highly convex anterior border. Anterior border furrow bifurcates producing a narrow (sag.), slightly raised paradoublural band equal in transverse width to the maximum width of the glabella. Surface of test is densely covered with fine granules, concentrated most on anterior border. Preglabellar field is also covered with faint anastomosing caecal marks.

Pygidium is large and approximately twice as wide as long. Axis is broken on all specimens of the pygidium, but occupies approximately two thirds of total length, is slightly tapered and possesses three or four axial rings and a short crescentic terminal piece. At least four pleural furrows and three interpleural furrows are present. Axial area of pygidium is convex, with the broad border strongly concave. Margin has pronounced median embayment.

Doublure is well developed, narrowing sharply with the median embayment and covered with terrace lines.

Discussion - Resser (1938, pl. 9, fig. 5, pl. 9, fig. 6, pl. 8, fig. 58, and pl. 6, figs. 14, 15) illustrated several species from the Conasauga Group of the southern Appalachians that he assigned to the poorly known genus *Amecephalina* Poulsen 1927, including *A.* bella, *A. convexa*, *A. coosensis*, *A. curticei* and *A. poulseni*. However, all of these species are comparable to *Glyphaspis* and are questionably assigned here to this genus. The material from the Pika is most similar to *G.*? *curticei* (Resser 1938, pl. 8, figs. 59, 60) however the cranidium of *G.*? cf. *curticei* is broader than that of *G.*? *curticei* , with broader fixed cheeks and shorter palpebral lobes. The pygidium of *G.*? *curticei* has a similar outline, although the median indentation is less well developed.

Genus *Spencella* Rasetti 1963

Type species - *Spencella montanensis* Rasetti 1963 from the Meagher limestone of Montana (by original designation).

Spencella cf. *montanensis* Rasetti 1963

(Pl. 2, figs. 4a, 5)

Spencella montanensis Rasetti 1963, pl. 68, figs. 1- 11.

Occurrence - Pika Formation, Windy Point (GSC loc. 52576).

Material - 10 cranidia.

Description - Cranidium is convex, and subrectangular in outline. Glabella is convex and somewhat inflated and anteriorly rounded. Axial, preglabellar and occipital furrows are all deeply impressed, with the axial furrows converging anteriorly. Glabellar furrows are almost completely effaced. Occipital ring is smooth and curved. Facial sutures are slightly convergent anteriorly, more strongly divergent posteriorly. Palpebral lobes are short and crescentic, located opposite glabellar midpoint on larger specimens. Palpebral ridge is faint. Frontal area is short and is divided into a very short downsloping preglabellar field and a longer, sharply upturned anterior border. Convex fixed cheeks slope downwards rapidly away from the glabella. Surface of the cranidium is granulose where testate (see pl. 2, figs. 5,6). Small specimens are less convex, with fixed cheeks that are wider posteriorly and narrower anteriorly.

Discussion - *Spencella montanensis* (Rasetti 1963, pl. 68, figs. 1-11) has a faint occipital node and usually has a glabella that is more rectangular in outline than most specimens of *S. cf. montanensis*, but is otherwise identical. However, the glabella of the specimen illustrated by Rasetti (1963, pl. 68, fig. 5) resembles the Alberta specimens more closely. *S. virginica* (Rasetti 1963, pl. 68, figs. 19-21) has much wider fixed cheeks and more anteriorly located palpebral lobes. *S. spinosa* (Rasetti 1963 pl. 68, figs. 12-15) possesses a distinct occipital spine, and its glabellar furrows are more deeply impressed. *S. acanthina* (Palmer 1968 pl. 5, figs. 18,19) also possesses an occipital spine, but is otherwise similar to *S.* cf. *montanensis*.

Spencella ? cf. *virginica* (Resser)

(Pl. 2, figs. 4, 6-8)

Solenopleurella virginica Resser 1938, pl.5, fig.4.

Spencella virginica Resser, Rasetti 1963, pl.68, figs. 19-21.

Occurrence - Pika Formation: Chaba River (GSC 72728-30), Windy Point (GSC 52576) and Roche Miette (RM-03).

Material - 67 cranidia.

Description - Cranidium is convex, and trapezoidal in outline. Glabella is convex and somewhat inflated and slightly anteriorly rounded. Axial, preglabellar and occipital furrows are all deeply impressed, with the axial furrows converging anteriorly. Glabellar furrows are almost completely effaced. Occipital ring is crescentic and possesses a small median node. Facial sutures are convergent anteriorly and divergent posteriorly, producing a nearly straight line. Palpebral lobes are short and crescentic, located well anterior of the glabellar midpoint. Palpebral ridge is faint. Frontal area is short and is divided into a very short to absentdownsloping preglabellar field and a longer, sharply upturned anterior border. Anterior border is medially inflated on some specimens producing a backwards curving of the anterior border furrow. Convex fixed cheeks slope downwards rapidly away from the glabella. Surface of the cranidium is granulose in some specimens (see pl.2, fig. 9).

Discussion The cranidia from the Pika Formation have anteriorly placed palpebral lobes comparable to *S. virginica* Rasetti (1963, pl. 68, figs. 19-21) but differs in that the palpebral lobes are much smaller and located closer to the glabella. For this reason, they are assigned only questionably to *Spencella*. *Spencella montanensis* Rasetti (1963, pl. 68, figs. 1-11) has a glabella that is more parallel - sided and less anteriorly rounded than *S.*? cf. *virginica* and its cranidium is more rectangular in outline than trapezoidal. *S. spinosa* Rasetti (1963 pl. 68, figs. 12-15) possesses a distinct occipital spine, and its glabellar furrows are more deeply impressed. *S. acanthina* Palmer (1968 pl. 5, figs. 18,19) also possesses an occipital spine and has more posteriorly placed palpebral lobes than *S.*? cf. *virginica*.

Some older species asssigned to *Plagiura* by Palmer and Halley (1979, pl. 6, figs. 21, 24-27) also have small, anteriorly positioned palpebral lobes that are located close to the glabella. It is possible that they are congeneric with *S.*? cf. *virginica*, but more infromation is needed about the rest of the exoskeleton in order to make a confident evaluation.

Gen. and sp. indet. 1

(Pl. 3, figs. 4-9)

Occurrence - Pika Formation; Chaba River (GSC locs. 72728, 29), Windy Point (GSC loc. 52576), Roche Miette (loc. RM-03).

Material - 63 cranidia and 19 pygidia.

Decsription - Glabella is trapezoidal in outline and slightly anteriorly rounded. Axial furrow is well developed, preglabellar furrow is narrow and occipital furrow is shallow. Three pairs of glabellar furrows are faintly impressed, 1s and 3s are oblique and 2s is transverse. Occipital ring is semicircular with faint median node. Palpebral lobes are sickle-shaped and up to two thirds of glabellar length. Palpebral ridges are faint. Fixed cheeks are narrow and slightly convex, with posterior cheeks sloping away from the glabella. Facial sutures are anteriorly divergent producing a broad frontal area, approximately equally divided into slightly downsloping preglabellar field and sharply upsloping anterior border. Border is separated by a weakly developed curved anterior border furrow. Surface is faintly granulose in some specimens, possibly an artifact of preservation.

Pygidium is semi-circular to sub-elliptical in outline. Axis is broad, occupies 0.8x length, and has 3 or 4 axial rings and a terminal piece. Four pairs of pleural furrows are well defined, the anteriormost being gently curved, and the degree of curvature increasing posteriorly, until the fourth furrow which is recurved inwards. Three pairs of interpleural grooves are discernible, the anteriormost of which cuts diagonally across the second segment. Margin has

three pairs of short triangular spines, each extensions of pygidial segments, with no interruption at the margin. Doublure is long and covered with terrace lines extending to the spines (see pl. 3, fig. 5)

Discussion - Some features with taxonomic implications are well expressed. The subrectangular glabella, the long and sickle-shaped palpebral lobes, the long concave frontal area and the relatively large pygidium with the broad doublure are comparable to genera of the Anomocaridae (Westerg_rd 1950, pl. 3, figs. 1-11). However, the lack of baculae (see also *Glyphaspis* discussion) separates this genus from the Anomocaridae. The pygidial morphology is, however distinct from the Anomocaridae, whose pygidia tend to have smooth margins (eg. *Anomocare* and *Anomocarina* Westerg_rd 1950 pls. 3, 4.) as opposed to the distinctively spinose character of gen. and sp. indet. 1. The pygidium resembles those assigned to *Marjumia* (Robison 1964a, pl. 87, figs. 5-10), however the outline of the pygidium of gen. and sp. indet. 1 is more semi-circular than sub-elliptical. Additionally, the marginal spines of gen. and. sp. indet. 1 are flat, as opposed to rounded in *Marjumia* and the first pleural segment overlaps the second, a feature that is not apparent in *Marjumia*. Finally, the pygidial doublure of gen. and sp. indet. 1 is broad and flat, rather than narrow and convex, as in *Marjumia* (see Robison 1964a, pl. 87, fig. 18). The cranidium resembles those assigned to *Glyphaspis tetonensis*, (pl. 4, figs 1-12, pl. 5, figs. 1-10), although the palpebral lobes are more sickle-shaped. The pygidial doublure is broad, similar to *G. tetonensis* and *G.*? cf. *G.*? *curticei*. Thus a relationship with *Glyphaspis* is also a possibility.

Gen. and sp. indet. 2

(Pl. 2, fig. 21)

Occurrence - Pika Formation, Chaba River (GSC loc. 72733).

Material - 3 cranidia.

Description - Cranidium is small and convex. Glabella is inflated, bullet-shaped in outline, convex and occupies 80% of cranidial length. Axial and occipital furrows are deeply impressed, and preglabellar furrow is weakly impressed. Occipital ring is crescentic. Short, slightly crescentic. Palpebral lobes are located at glabellar midlength and are attached to well defined, oblique palpebral ridges. Fixed cheeks are convex and half as wide as the glabella. Short, downsloping preglabellar field connects with the slightly longer, upturned anterior border. Surface of test is finely granulose.

Discussion - This trilobite most closely resembles gen. and sp. indet. 2 Robison (1964a, pl. 89, fig. 18) from the *Bolaspidella contracta* Subzone of the Marjum Formation. As the two trilobites are from apparently correlable strata, it is possible that they are conspecific.

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PLATES

All specimens were blackened with india ink and then coated with a sublimate of ammonium chloride prior to photography

PLATE 1

Olenoides cf. *pugio* Walcott, 1908. Pika Formation.

1. Pygidium, dorsal view, GSC loc. 72743, x4.5.
2. Cranidium, dorsal view, GSC loc. 72742, x6.

3,5 Cranidium, dorsal and oblique views, GSC loc. 72744, x6.

4. Pygidium, dorsal view, GSC loc. 72742, x4.5.
6. Hypostome, ventral view, GSC loc. 72742, x6.

Marjumia cf. *transversa* Palmer, 1968. Pika Formation.

7,9 Cranidium, dorsal and ventral views, GSC loc. 72729, x4.5.

8. Cranidium, dorsal view, GSC loc. 72728, x4.5.
9. Cranidium, oblique view, GSC loc. 72729, x4.5.
10. Pygidium, dorsal view, GSC loc. 72729, x4.5.
11. Pygidium, dorsal view, GSC loc. 72729, x4.5.
12. Pygidium, dorsal view, GSC loc. 72729, x4.5.
13. Free cheek, dorsal view, GSC loc. 72729, x 6.


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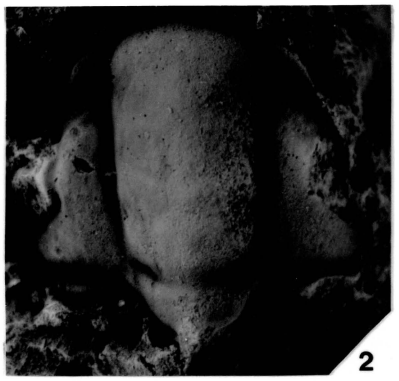
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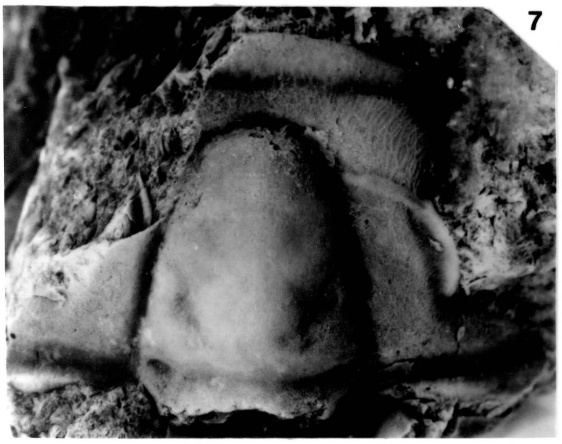
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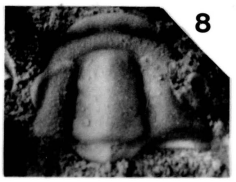
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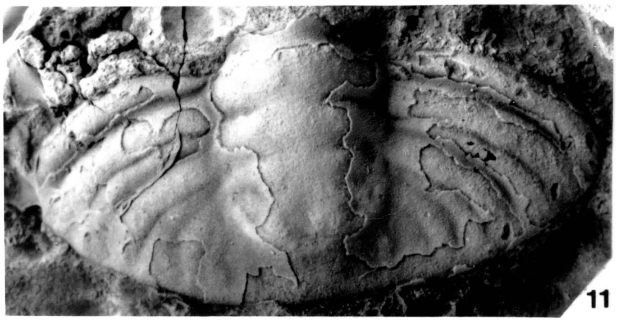
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PLATE 2

Bolaspidella resseri (Miller 1936) Pika Formation

1-2. Cranidium, dorsal and oblique views, GSC loc. 72732, x9.

3. Cranidium, dorsal view, GSC loc. 52577, x9.

Spencella? cf. *virginica* Rasetti, 1963. Pika Formation

4. Cranidium, dorsal view, GSC loc. 52576, x9.

6. Cranidium, dorsal view, GSC loc. 52576, x9.

7-8. Cranidium, dorsal and oblique views, GSC loc. 52576, x9.

Spencella cf. *montanensis* Rasetti, 1963. Pika Formation

4a. Cranidium, dorsal view, GSC loc. 52576, x9.

5. Cranidium, dorsal view, GSC loc. 57576, x9.

Glyphaspis sp. 2 Pika Formation

9. Cranidium, dorsal view, RMF 20.4+, x4.

10. Pygidium, dorsal view, RMF 20.+, x4.

Marjumia bagginsi sp. nov. Pika Formation

11. Cranidium, dorsal view, GSC loc. 52576, x9

12. Pygidium, dorsal view, GSC loc. 52576, x5.5.

13,16. Cranidium, dorsal view, GSC loc. 52576, x5.

14. Cranidium (slightly tectonised?), dorsal view, GSC loc. 52576, x5.

15. Pygidium, dorsal view, GSC loc. 52576, x5.5.

17. Pygidium, dorsal view, RM-03, x5.5.

18. Pygidium, dorsal view, 52576, x5.5.

Marjumia? sp.

19. Cranidium, dorsal view, GSC loc. 72743, x7.5.

20. Pygidium, dorsal view, GSC loc. 72742, x7.

Gen. and sp. indet. 2

21. Cranidium, dorsal view, GSC loc. 72733, x9.


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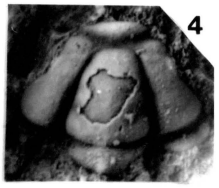
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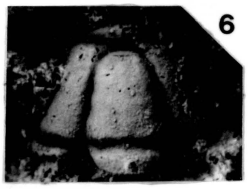
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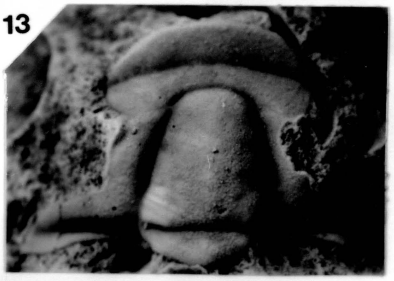
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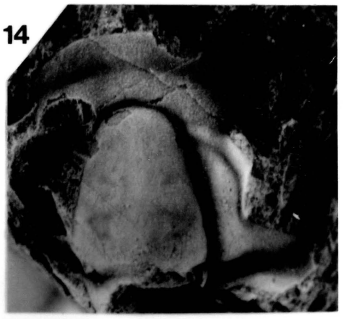
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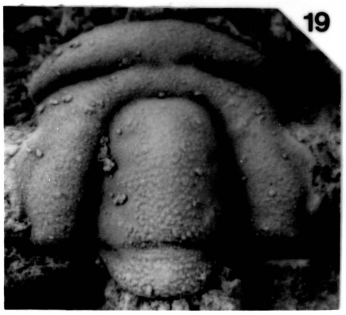
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PLATE 3

Glyphaspis? cf. *curticei* (Resser 1938) Pika Formation

1. Pygidium, dorsal view, GSC loc. 72732, x4.
2. Pygidium, dorsal view, GSC loc. 72732, x4.

3,6 Cranidium, dorsal and oblique views, GSC loc. 72731, x4.5.

Gen. and sp. indet. 1 Pika Formation

4. Cranidium, dorsal view, GSC loc. 52576, x7.5.
5. Pygidium, dorsal view, GSC loc. 72728, x7.5.
7. Pygidium (exfoliated), dorsal view, GSC loc. 72728, x7.5.

8,9. Cranidium, dorsal and oblique view, GSC loc. 72729, x7.5.

PLATE 4

Glyphaspis tetonensis (Lochman and Hu 1960) Pika Formation

1. Pygidium, dorsal view, GSC loc. 72739, x4.5.
2. Cranidium, dorsal view, GSC loc. 72739, x5.
3. Cranidium, dorsal view, GSC loc. 72739, x5.
4. Pygidium, dorsal view, GSC loc. 72739, x.4.5.
5. Free cheek (fragmentary), ventral view, GSC loc. 72738, x8.
6. Rostral plate, ventral view, GSC loc. 72736, x8.
7. Free cheek, dorsal view, GSC loc. 72739, x6.
8. Rostral plate, ventral view, GSC loc. 72736, x8.
9. Hypostome, ventral view, GSC loc. 72739, x8.
10. Hypostome, ventral view, GSC loc. 72739, x8.
11. Hypostome, ventral view, GSC loc. 72739, x8.
12. Pygidium, dorsal view, GSC loc. 72739, x4.5.

Knechtelia festiva (Lochman and Hu 1960) Pika Formation

13, 15, 16. Cranidium, oblique, dorsal and anterior views, GSC loc. 72738, x9.

14. Cranidium, dorsal view, GSC loc. 72736, x8.
17. Cranidium, dorsal view, GSC loc. 72738, x8.
18. Cranidium (tectonised?), dorsal view, GSC loc. 72740, x8.

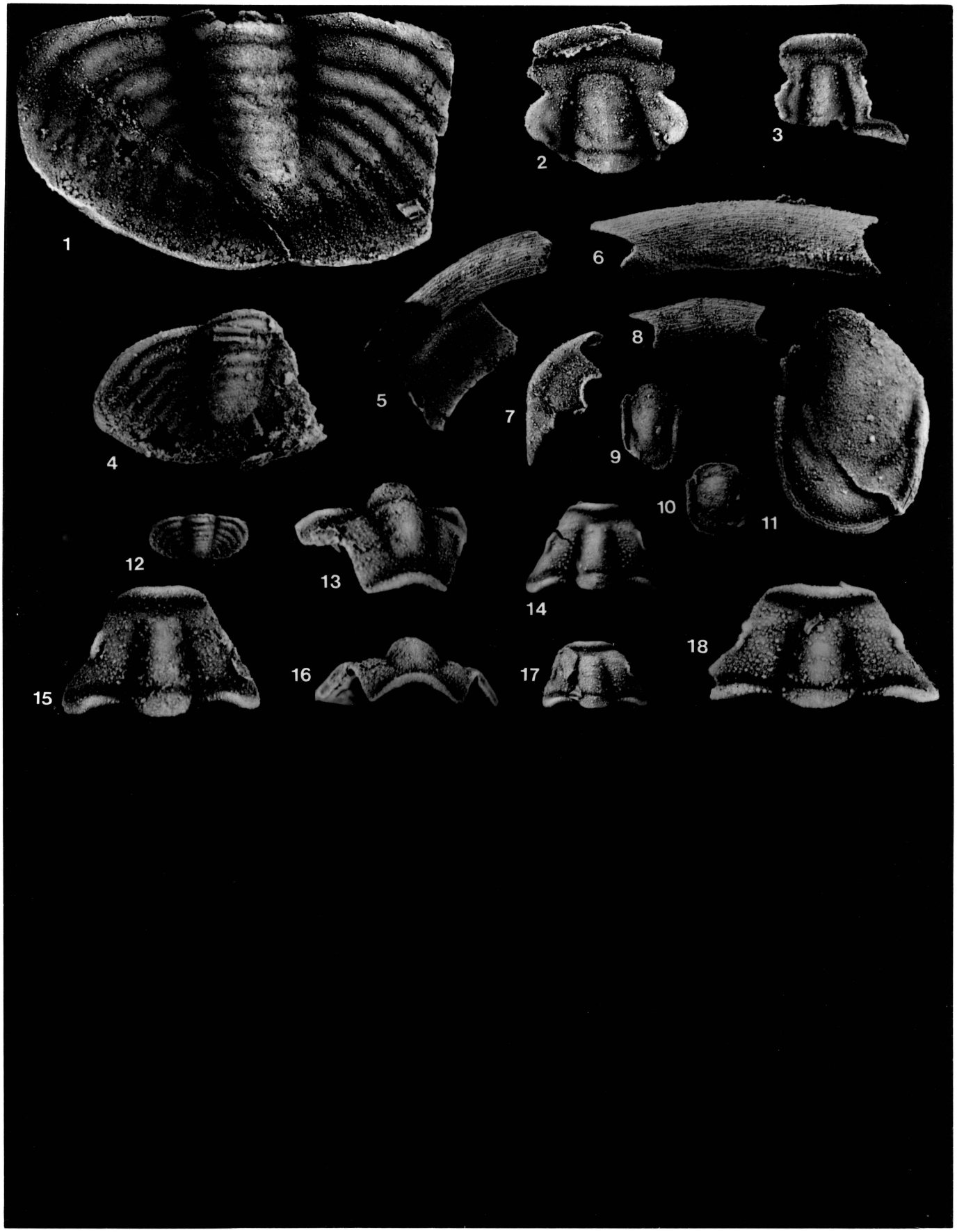
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PLATE 5

Glyphaspis tetonensis (Lochman and Hu 1960) (All from GSC loc. 72741) Pika Formation

1. Cranidium, dorsal view, x4.5.

2,4. Cranidium, dorsal and oblique views, x4.5.

3, Cranidium, dorsal view, x4.5.

5. Free cheek, dorsal view, x5.

6. Pygidium, dorsal view, x6.

7. Pygidium, dorsal view, x6.

8. Hypostome, ventral view, x8.

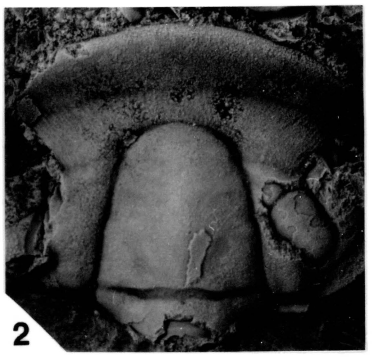
9. Cranidium, dorsal view, x4.5.

10. Pygidium, dorsal view, x6.

Glyphaspis sp.1 Pika Formation

11,12. Cranidium, oblique and dorsal views, GSC loc. 72743, x7.5.


1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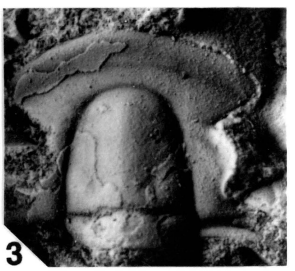
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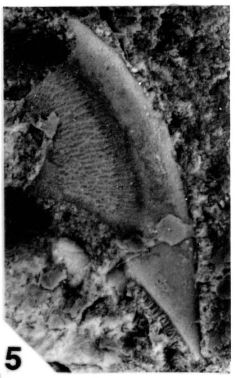
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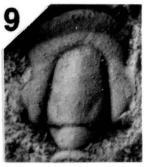
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10


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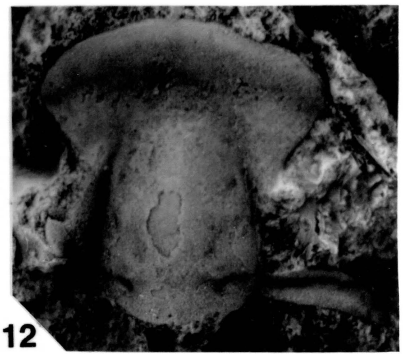
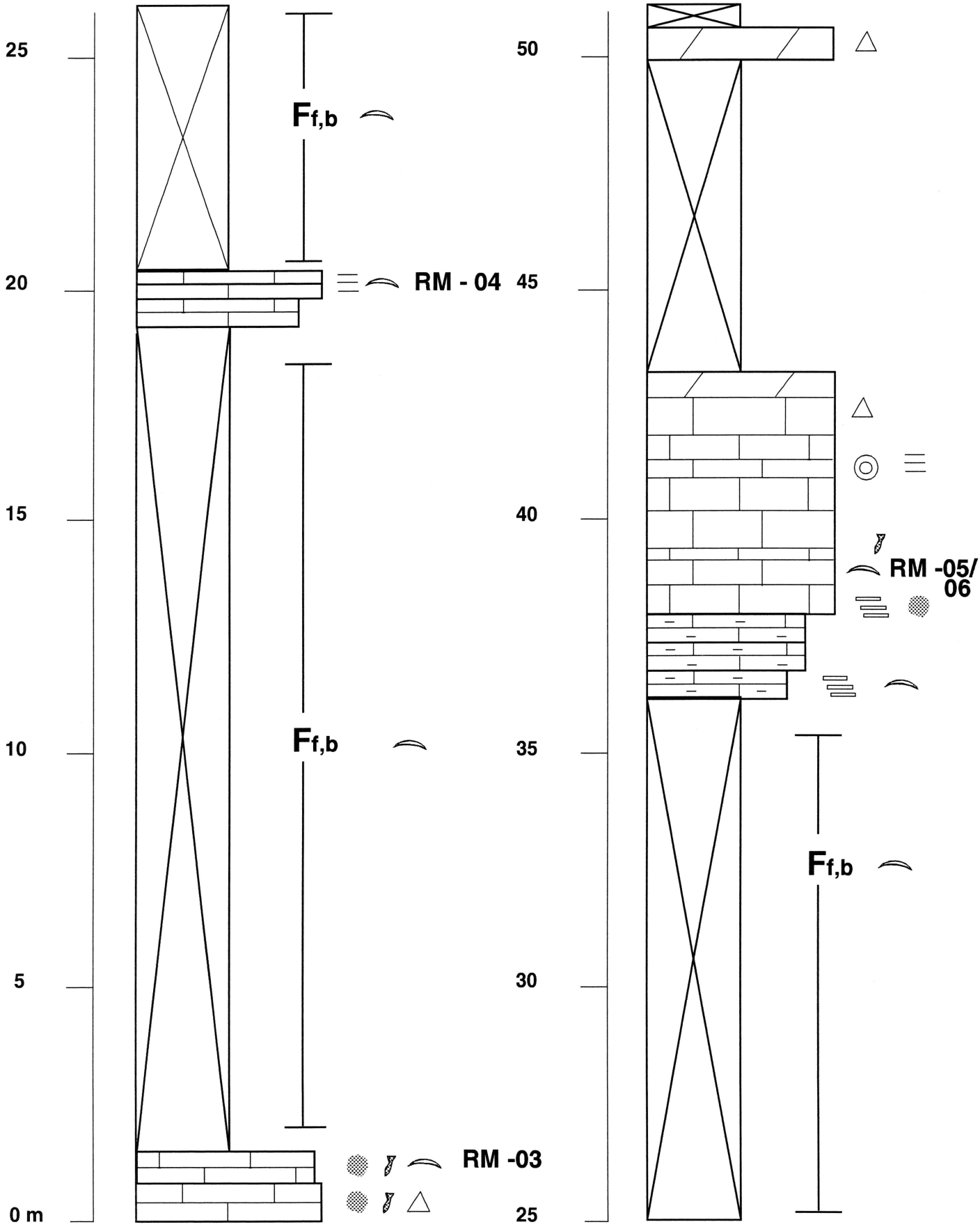

12

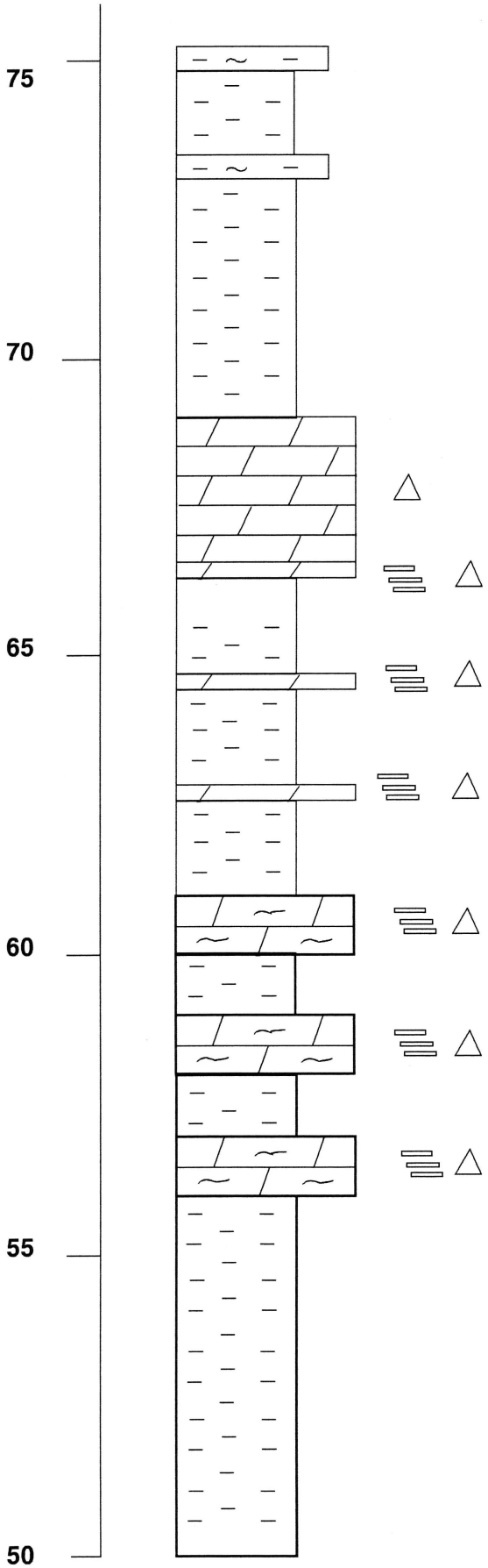
APPENDIX 1

Roche Miette

This section was measured on the spur north of Roche Miette at the same site as AC - 142 measured by J.D. Aitken of the G.S.C. (Aitken 1966a).

	Cranidia	Pygidia	Individuals
RM - 02			
Coquina of weathered free cheeks			
RM - 03			
Marjumia bagginsi	3	4	4
Spencella? cf. *virginica*	2		2
Gen. and sp. indet. 1	1	3	3
RM - 04			
RMF 20.4+			
Glyphaspis sp. 2	19	6	19
RM - 05/06			
Glyphaspis sp. 2	91	7	91
RM - 07			
Badly weathered coquina of *Glyphaspis* cranidia and pygidia.			


25
20
15
10
5
0 m
Ff,b
RM - 04
Ff,b
RM -03
50
45
40
35
30
25
RM -05/
06
Ff,b

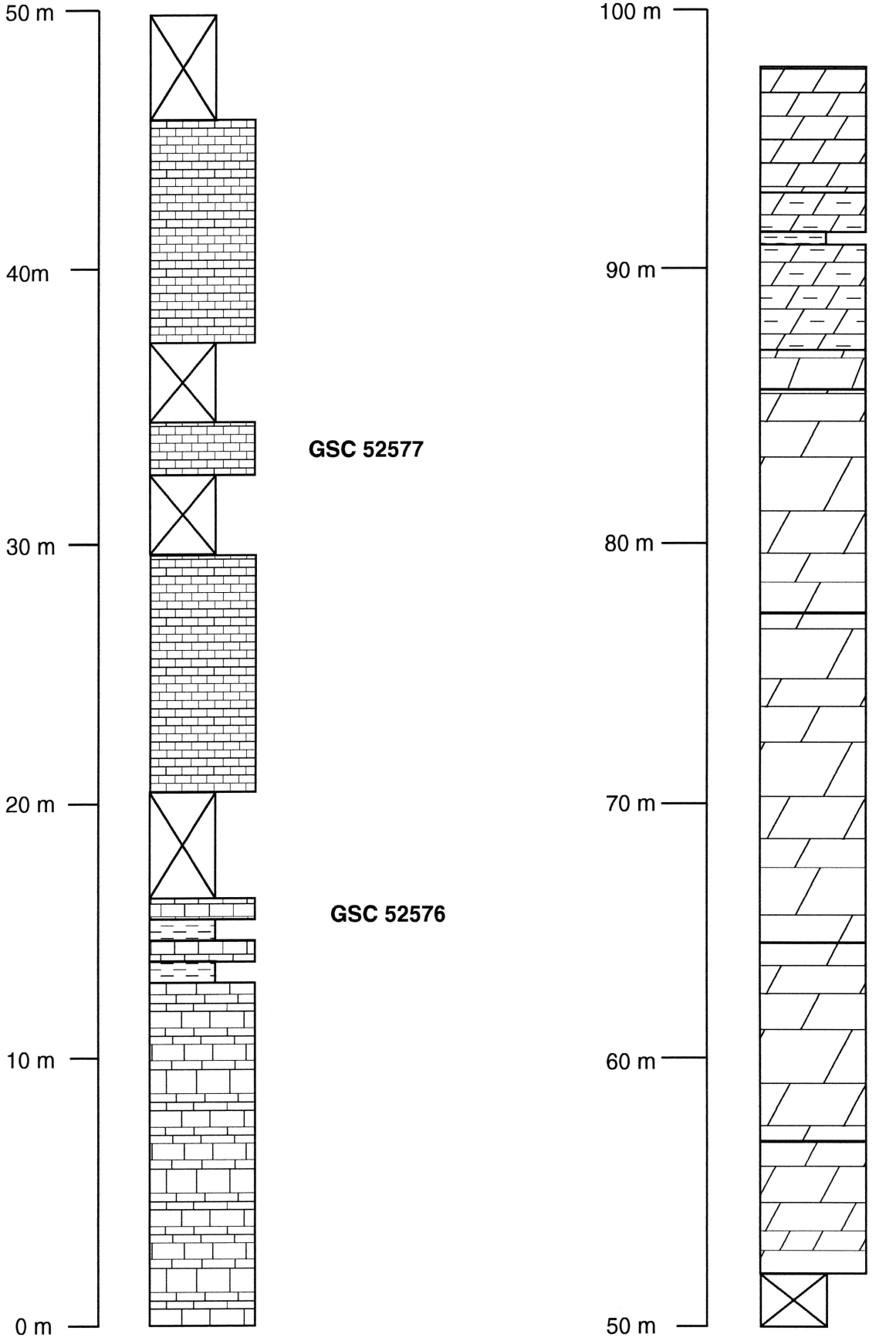

75
70
65
60
55
50

APPENDIX 2

Windy Point

This section was measured south of Mount Tershisner near the David Thompson Highway by J.D. Aitken of the G.S.C. (Aitken 1966).

	Cranidia	Pygidia	Individuals
52576			
Marjumia bagginsi	116	21	116
Spencella? cf. *virginica*	25		25
Spencella cf. *montanensis*	10		10
Gen. and sp. indet. 1	43	13	43
52577			
Glyphaspis sp. 2	149	17	149
Bolaspidella resseri	34		34
52577b			
Glyphaspis sp. 2	405	7	405
Bolaspidella resseri	8		8


50 m
40m
30 m
20 m
10 m
0 m
GSC 52577
GSC 52576
100 m
90 m
80 m
70 m
60 m
50 m

APPENDIX 3

Chaba River

This section was measured and collected by Drs. Fritz and Aitken of the G.S.C. near Chaba River (52 18', 117 47').

	Cranidia	Pygidia	Individuals
72728			
Marjumia cf. *transversa*	12	5	12
Spencella? cf. *virginica*	4		4
Gen. and sp. indet. 1	3	3	3
72729			
Marjumia cf. *transversa*	94	31	94
Spencella? cf. *virginica*	18		18
72730			
Marjumia cf. *transversa*	4	1	4
Gen. and sp. indet. 1	4	1	4
72731			
Bolaspidella resseri	3		3
Glyphaspis? aff. *A. curticei*	8	7	8
72732			
Bolaspidella resseri	1		1
Glyphaspis? aff. *A. curticei*	11	9	11

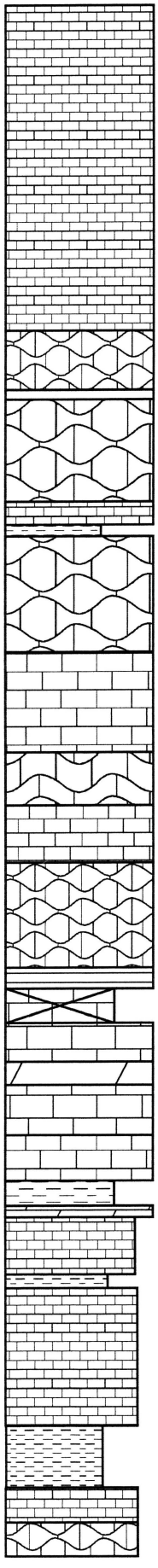
72733			
Gen. and sp. indet. 2	3		3

Several unidentifiable sclerites were also found in this collection.

Collections 72736-41 contained well preserved silicified material.

72736			
Glyphaspis tetonensis	24	61	61
Knechtelia festiva	5		5
72737			
Glyphaspis tetonensis	69	100	100
72738			
Glyphaspis tetonensis	57	91	91
Knechtelia festiva	9		9
72739			
Glyphaspis tetonensis	246	400	400
72740			
Glyphaspis tetonensis	79	101	101
Knechtelia festiva	39		39
72741			
Glyphaspis tetonensis	102	139	139
Knechtelia festiva	11		11

72742			
Olenoides cf. *pugio*	29	15	29
Marjumia sp.	20	4	20
Glyphaspis sp.	9		9
72743			
Olenoides cf. *pugio*	9	9	9
Marjumia sp.	8		8
Glyphaspis sp. 2	6	2	6
72744			
Olenoides cf. *pugio*	6	5	6
Marjumia sp.	1		1



72741
72740

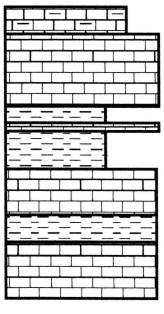
72739

72738

72736-72737

72731-72735

72730
72729
72728



72743-44

72742

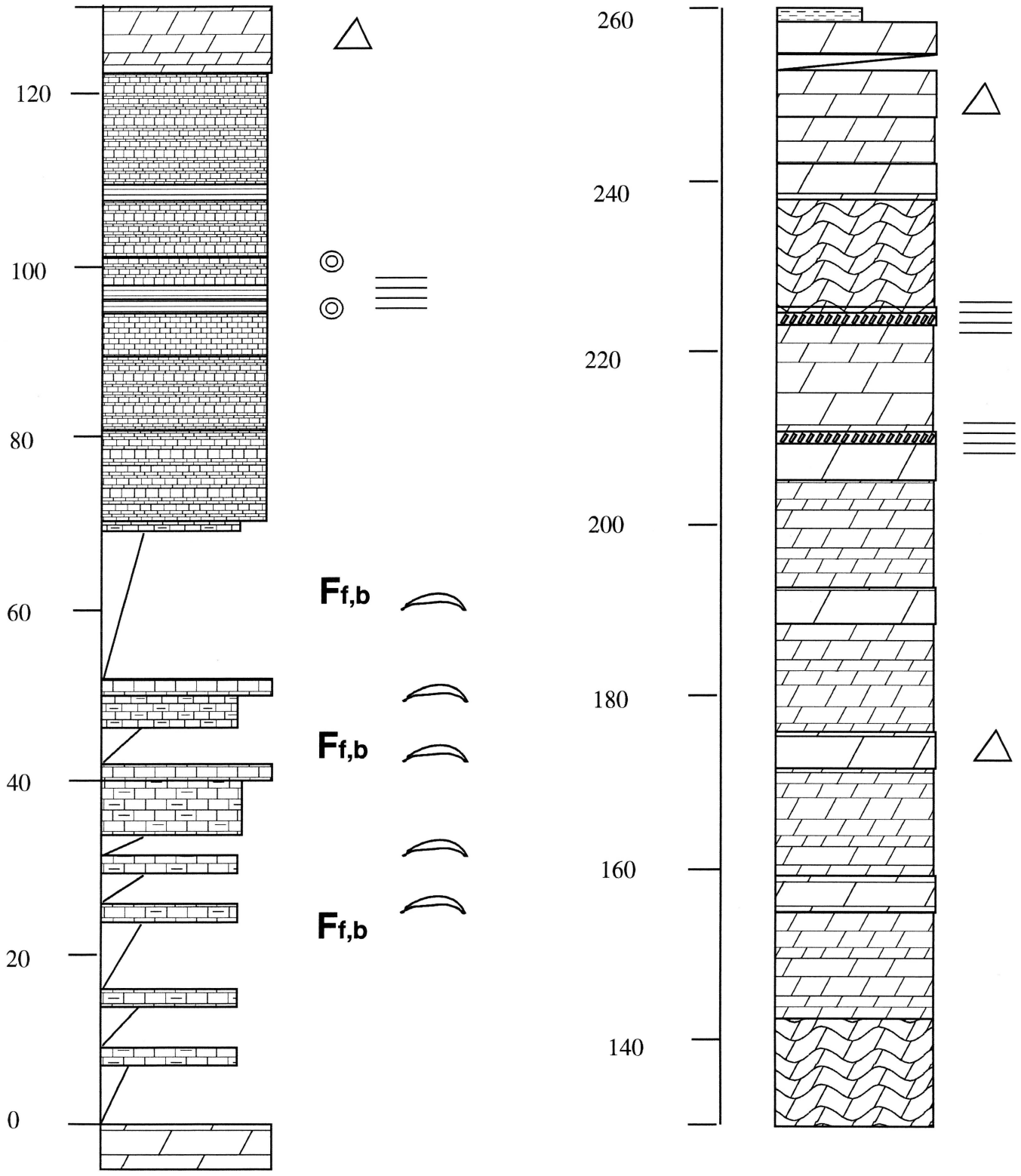
300 m

APPENDIX 4

Mount Weed

This section was measured south of Mount Weed near Silverhorn Creek in Banff National Park.

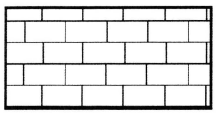
All fossils from this section were poorly preserved on weathered bedding surfaces and provided no taxonomic information.

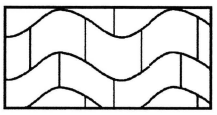

120
100
80
60
40
20
0
Ff,b
Ff,b
Ff,b
260
240
220
200
180
160
140

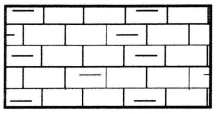
APPENDIX

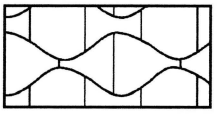
Lithologic Sections

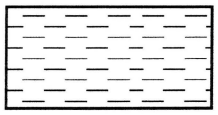
Legend

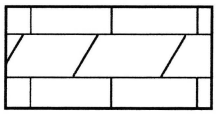

Limestone

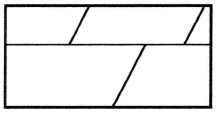

Wavy limestone

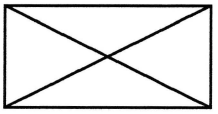

Argillaceous lime mudstones


Nodular wackestones/ packstones

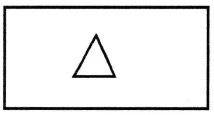

Shales/Mudstones

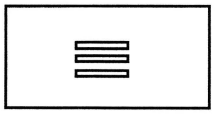

Dolomitic packstones/ grainstones


Massive dolostones

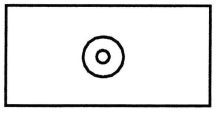

Covered interval

The following symbols are used in section diagrams:

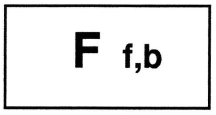

Recrystallization


Flat pebble conglomerate

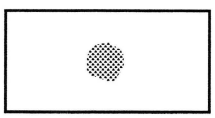

Bioclasts


Oolites


Cryptalgalaminite



Float (flaggy, bioclastic)


Dolomitic mottling


Bioturbation